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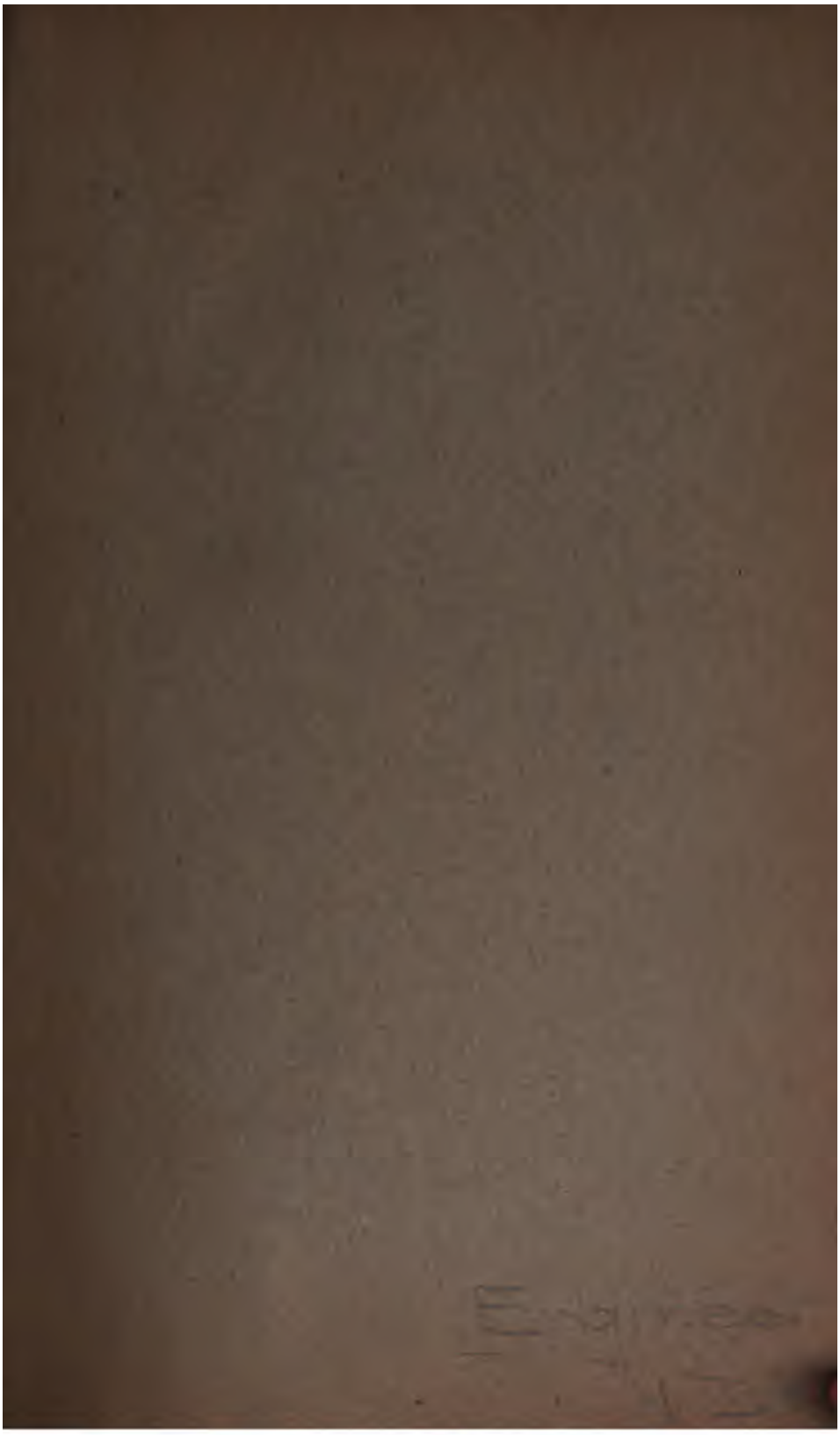

TRANSACTIONS

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OF

Western Pennsylvania.

INCORPORATED JANUARY, 1880.

VOL. I.

JANUARY, 1880, to JUNE, 1882.

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WHY DOES STEEL HARDEN?

By Wm. Metcalf, C. E.

[Read January 20, 1880.]

In a late number of *Engineering* Mr. Jas. Nasmyth expresses surprise that so little attention has been paid to the important property of steel known as "hardening."

The numerous replies informing him how steel hardens, and why steel hardens, show that much attention has been paid to the subject, and that the "whys" given are as numerous as the writers.

Perhaps Mr. Nasmyth has not given much attention to the question himself, and is therefore unconscious of the fact that his "why" may be as deep a mystery and as entirely unanswerable as any other of the multitude of the "whys" in nature, no one of which has yet been solved.

It is not the intention of this paper to give an answer to the question as Mr. Nasmyth puts it, which is possibly unanswerable; but to state what has been done, in the way of gathering facts, preparatory to an attempt to determine what are the chemical or physical changes which occur in the phenomena of hardening, tempering and annealing of steel.

The inquiry has been pursued diligently by Prof. Jno. W. Langley and ourselves for the past five years, and has been directed exclusively to the gathering of facts, so that as yet we have not even a theory to offer. The inquiry may be divided as follows:

1. The physical structure of steel.
2. The chemical composition.
3. The variations of structure and physical properties due to—

a.—Cooling from fusion.

b.—Effect of work, either by rolling or hammering.

c.—Effects of temperature, and of changes from one temperature to another, as shown by slow cooling.

4. A statement of the various theories of hardening.
5. Some practical conclusions for workers of steel.

1. The physical structure of steel.

In this paper it is to be understood that reference is made only to cast steel.

Steel is crystalline in structure. The size, color and form of the crystals, when steel is allowed to cool without hindrance, from a state of fusion, are governed by its chemical constitution, and are mainly influenced by the quantity of carbon present.

2. The chemical composition of steel.

Steel is mainly an alloy, compound, or mixture of iron and carbon.

Exactly which of these it may be, or whether it is a combination of two or of all three of these conditions it is difficult to say.

Other elements, as silicon, phosphorus, sulphur, manganese and so on, are as yet present only by sufferance, and generally, it is well known that steel is better without any of them.

The range of carbon in commercial steel may be said to be from about 0.05 per cent. to 1.75 or 2 per cent., but for some purposes of this inquiry we may look at several properties of cast iron as being useful to throw light on the subject.

3. The variations of structure and physical properties due to—

a.—Cooling from fusion—as affected by chemical composition, temperature, and rate of cooling.

The structure of steel, and of cast iron, as shown in a fresh fracture of the ingot in one case, or the pig in the other, are remarkable as always indicating the quantity of carbon present, the temperature at which the metal was poured, and the rate of cooling.

As the observation of these phenomena furnishes material for the study of a lifetime, and as they cannot be described properly without the objects themselves, only a few well known facts will be mentioned, for use in the latter part of this paper. Cast iron when poured into iron molds, hardens just as steel does when quenched in water ; this is known as "chilling."

A chill is of silvery white color, bright luster, and consists of elongated crystals generally normal lengthwise to the surface of the mold.

If iron contains little or no silicon, it will chill very deep, or entirely through the mass in small castings.

If much silicon be present it will not chill at all.

If a hard chill, for instance in a hammer die,—say two inches thick of chill, be brought to a heat, removed from the fire at once and allowed to cool slowly, it will, when broken, be found to be softened, but it will retain the marked crystalline form of the chill. This is analogous to tempered steel.

If the same chill be heated red, and kept red hot for several hours, and then cooled slowly, it will be found upon breaking to be an entirely amorphous gray cast iron ; every trace of the elongated crystals of the chill will have disappeared.

This is analogous to annealed steel. This experiment is a striking example of iron and combined carbon in the one case, and of iron and graphite carbon in the other case ; as these conditions are commonly understood.

This observation is useful in understanding similar changes which occur in steel under the similar conditions of hardened, tempered and annealed steel.

Steel when cast is almost invariably poured into iron molds, and the study of fractured ingots is very necessary to the steel maker ; but as the ingots very rarely go into the hands of the consumer without previous manipulation, it is hardly necessary to consume time in discussing the characters of the fractures, especially as it requires the actual presence of the ingots to make the description at all intelligent.

It is sufficient to say that we have here an unvarying record of the completeness or incompleteness of the fusion, of the rate and temperature of the pouring, and of the chemical character of the steel, especially as it relates to carbon.

b.—Effect of work either by hammering or rolling.

Steel when heated and hammered or rolled from the ingot has its specific gravity largely increased, its strength is greatly increased, and its grain is made very fine and uniform ; this is called "hammer refining," to distinguish it from the refining due to hardening.

An eminent Russian engineer has illustrated this hammer refining beautifully by comparing the hot steel to a certain solution of salt.

If the solution be allowed to precipitate slowly and undisturbed, very large crystals will be formed, but if it be violently shaken the crystallization is hastened and very fine crystals are formed.

So if steel be heated quite hot, but not so as to burn it, and be

allowed to cool very slowly, it will form in very large bright crystals and be very friable ; but if as soon as it is hot it be taken to a heavy hammer and be thoroughly hammered by rapid and powerful blows at first, and then by lighter blows until it is of the required shape, it will be found to be very fine in grain and very strong.

Therefore, a high softening heat is consistent with good work in forging.

c.—Effects of temperature, and of changes from one temperature to another, as shown by slow cooling or rapid cooling.

The effect of heating steel which has been hammered or rolled is to increase the size of the crystals or grain, in proportion to the temperature, and to reduce the specific gravity. There is an apparent or real exception to this increase in size of grain, in steel which has been hardened from the proper temperature to produce what is known as "refining."

In this case the grain is much finer than in the bar, and in this condition any piece of hardened and tempered steel is at its best.

As this refining temperature varies with every different quantity of carbon, no rule can be laid down for determining it ; it must be found by actual trial.

But there is no exception in the matter of specific gravity. The specific gravity of refined steel is less than that of the bar, although the grain is much finer. If steel be heated and cooled slowly it will be softened ; that is, annealed.

If it be heated very hot, say to bright yellow, or kept hot a long time, and then cooled slowly, it will still be annealed, but it will be harsh and gritty, will not cut well, and will neither refine well when hardened nor hold a good edge when tempered. The cause of this will be obvious if we remember the experiment of the annealed chill mentioned in the earlier part of this paper. If steel be heated to different degrees, as red, bright red, orange, lemon or bright yellow color, and quenched, it will be found to be harder, more brittle and coarser in the grain for each increasing degree of heat, after the "refining" heat has been passed. Below the "refining" heat there will be no useful degree of hardening, and the grain will be variable.

If any piece of hardened steel be heated red hot, and cooled slowly, it will be softened, the grain of the steel will return to its original appearance in the bar, and its specific gravity will be restored to the specific gravity of the bar.

This fact should put a quietus upon all quack nostrums for "restoring burnt steel."

If a piece of steel containing little carbon be alternately hardened, and heated and rehardened a number of times, it will vary in volume, but will not sustain regular increases of volume.

If steel of moderately high carbon be repeatedly hardened, it will continue to increase in volume until ruptured. This will be illustrated by table No. 5.

Some years ago twelve ingots were selected by numbers and analyzed to determine the accuracy of ocular inspection, and were afterwards experimented upon in following up the search for facts in regard to the cause of "hardening."

The specific gravities of these ingots were determined, and the results were given by Prof. Langley in a paper read before the American Association for the Advancement of Science, in 1876. Since then bars rolled from these ingots have been experimented upon, and the specific gravities of the bars, and of various hardened pieces and of re-softened pieces have been determined.

These experiments will now be described.

Table I. gives the analyses and specific gravities of the ingots.

Table II. gives the specific gravities of six of the bars, and the specific gravities of the same bars heated to various temperatures and hardened.

Table III. gives the specific gravities of the six bars, and the six hottest pieces numbered 1 in table II., after having been annealed from the condition given in table II.

TABLE I.

INGOT NUMBERS.	C.	Si.	Ph.	S.	Fe. by Difference.	Sp. Gr. ingots.
1.....	.302	.019	.047	.018	99.614	7.855
2.....	.490	.034	.005	.016	99.455	7.836
3.....	.529	.043	.047	.018	99.363	7.841
4.....	.649	.039	.030	.012	99.270	7.829
5.....	.801	.029	.035	.016	99.119	7.838
6.....	.841	.039	.024	.010	99.086	7.824
7.....	.867	.057	.014	.018	99.044	7.819
8.....	.871	.053	.024	.012	99.040	7.818
9.....	.955	.059	.070	.016	98.900	7.813
10.....	1.005	.088	.034	.012	98.861	7.807
11.....	1.058	.120	.064	.006	98.752	7.803
12.....	1.079	.039	.044	.004	98.834	7.805

Table IV. gives the specific gravities of four pieces all from the same bar after various treatment.

Table V. gives the results of repeated hardening of three pieces of steel containing different quantities of carbon.

Consideration of the tables :

Table I. contains the analyses of twelve ingots numbered in the left hand column from 1 to 12.

The ingots were selected by the eye and numbered as in the table by Mr. Charles Parkin, with a view to varying quantities of carbon only.

It will be seen that the carbon increases with the numbers regularly, but not uniformly.

Although a repetition of the analyses of Nos. 7 and 8 confirmed Prof. Langley in the correctness of his figures, it must be admitted that in this case Mr. Parkin was quite as lucky as skillful, for it is hard to believe in a really observable variation of structure due to a difference of only 0.004 carbon.

In the columns for Si., Ph. and S. the entire absence of progressive quantities shows clearly that these elements had nothing to do in determining the characteristic fractures.

The column of iron by difference happens to run with the carbon column, except in No. 11, where the series is broken by the abnormal amount of Si. in that ingot. Theoretically, of course, the specific gravities should run with the iron by difference, but they do not do so in ingots 3 and 5. These, however, are the only exceptions ; this may have been caused by incomplete or unusually hot melting, or by hot or cold pouring, or by slow or fast pouring.

These exceptions do not vitiate the rule, and only show that no one set of experiments can be conclusive.

TABLE II.

	Sp. Gr. Pig.	Sp.Gr Bar. No. 6.	Diff.	Sp.Gr Bar. Pc No 5.	From Bar. Diff.	Sp.Gr Bar. No. 4.	Diff. from Bar.	Sp.Gr Bar. No. 3.	Diff. from Bar.	Sp.Gr Bar. No. 2.		Sp.Gr Bar. No. 1.	Diff. from Bar.
3.....	7.841	7.844	.003	7.831	—.013	7.826	—.018	7.823	—.021	7.814	—.030	7.818	—.026
4. ...	7.829	7.824	—.005	7.806	—.018	7.849	025	7.830	.006	7.811	—.013	7.791	—.033
6.....	7.824	7.829	.005	7.812	—.017	7.808	—.021	7.780	—.049	7.784	—.035	7.789	—.040
8.....	7.818	7.825	.007	7.790	— 035	7.773	—.042	7.758	— 067	7.755	—.070	7.752	—.073
10.....	7.807	7.826	.019	7.812	—.014	7.789	—.037	7.755	—.071	7.749	—.077	7.744	—.082
12.....	7.805	7.825	.020	7.811	—.014	7.798	—.027	7.769	—.056	7.741	—.084	7.690	—.135
		6		5		4		3		2		1	
		Not heated.		Low red heat.		Red hot.		High red.		Yellow hot.		Nearly white Scintillating.	

The twelve ingots under consideration were hammered to 1¼ inch square bars at one end, and these bars were rolled to .625 diameter round bars.

Six of these bars, Nos. 3, 4, 6, 8, 10, 12, were selected for specific gravity tests ; bar No. 2 was lost or it would have been used instead of No. 3.

Six nicks were made around each bar at one end, at intervals of about half an inch.

The six pieces were numbered from 1 at the end to 6.

Each notched bar was then heated until piece No. 1 was scintillating or nearly white hot ; No. 2 was yellow hot ; No. 3 high red hot ; No. 4 red hot ; No. 5 barely showing any red, or very low red hot ; No. 6 black.

This heating was done in each case as slowly and as carefully as possible ; the results show the inevitable irregularities attending only one such experiment, yet there is enough of regularity to teach us a great deal.

As soon as the heats were obtained the bars were quenched in water.

The pieces, carefully numbered, both with the ingot numbers and with the numbers giving their order on the bars, were then broken off and sent to Prof. Langley to have the specific gravities determined. In the table the left hand column gives the ingot numbers.

The other columns give the specific gravities of the ingots, the bars—No. 6 pieces, and of the other five hardened pieces in order, as numbered in the sketch and explained before.

The differences are, first, the difference between the Sp. Gr. of the ingots and the bars ; second, the difference between the Sp. Gr. of the bar, or piece No. 6, and each piece successively.

The differences of Sp. Gr. are given in preference to the actual differences in volume, because the differences in volume run into the infinitesimals, and the mode adopted answers as well for purposes of comparison.

On comparing the ingot and bar we see a decided increase in the Sp. Gr. of the bar in every case except one, that of No. 4. We have not discovered the reason of this anomaly. The increase in the other cases is due to hot working ; this will be shown by table IV.

It will be observed that the Sp. Gr. of the bars, except in No. 3, are nearly uniform.

This seemed very strange at first, but it is capable of a very simple explanation. The hardness of steel and its resistance to change of form increase very rapidly with an increase of carbon, and as these bars were all reduced from 3 in. square ingots to $\frac{5}{8}$ in. round bars, it is obvious that it required much more work to reduce No. 12 than No. 4 or No. 6 ; therefore, as hot working increases Sp. Gr., the greater amount of work produced the greater increase in the Sp. Gr. of No. 12.

If the Sp. Gr. of the right hand column pieces No. 1 be compared to the Sp. Gr. of the ingots, it will be seen that the relation between the numbers is entirely restored by the high heat to which the No. 1 pieces were subjected.

If the Sp. Gr. of pieces No. 5, 4, 3, be examined carefully, sufficient irregularities in the difference columns will be observed to show that the heating was not accomplished in regular gradations in each case, and if it were desired to lay down an exact law of variation due to differences of temperature, it would be necessary to take the mean of a great many experiments.

Nevertheless, several general laws are indicated in this table.

1st. The Sp. Gr. of the ingot varies directly with the quantity of iron present.

2d. The greater the quantity of carbon present the greater is the amount of work necessary to produce change of form.

3d. The greater the quantity of carbon present the greater is the change in volume due to a change of temperature.

As for example, in No. 3 the change in Sp. Gr. from the ingot to the bar is only 0.003, and from the same bar to the piece No. 1 the change is 0.026.

While in No. 12 the change in Sp. Gr. from the ingot to the bar is 0.020, or about seven times that in No. 3, and the change from the bar to the piece No. 1 is 0.135, or about five times the change in No. 3.

This is perhaps the most important observation that can be made on this series of experiments, as it shows us why it is that high steel is so much more liable to crack and break in manipulation than low steel.

We generally say one is brittle and the other is ductile ; we now know that the rate of expansion per degree of temperature is much less in low steel than in high steel. Therefore, low steel is much less liable to injurious internal strains than high steel.

TABLE III.

Ingot Numbers.	Sp. Gr. of bars. No. 5.	Sp. Gr. of burned pieces annealed No. 1.	Diff.
3.....	7.844	7.857	+.013
4.....	7.824	7.846	+.022
6.....	7.829	7.835	+.006
8.....	7.825	7 828	+.003
10.....	7.826	7.824	—.002
12.....	7.825	7.822	—.003

In order to settle the question of restoring "burned steel," so called, and also to determine the reverse action due to annealing, Prof. Langley took the six pieces No. 1 of table II. and heated them all to a high yellow heat ; he then allowed them to cool very slowly.

This raised a heavy scale on the pieces which was removed by touching them on an emery wheel.

The specific gravities of these pieces were then taken, and the results are given in the table.

The restoration to the Sp. Gr. of the bar is complete, as the differences are only such as might be due to the scale on the original bars, and the removal of the scale from the annealed pieces. This will be shown further in table IV.

TABLE IV.

DRILL ROD SAMPLES.

Nos.	1 Sp. Gr.	2 Sp. Gr. Hardened.	3 Sp. Gr. Scaled and not hardened.	Diff. 3-2 Effect of hardening.	Diff. 3-1 Effect of scale off in 1 and 2.
1.....	7.8068	7.818	7.829	—.011	+.022
2.....	7.794	7.812	7.828	—.016	+.034
3.....	7.816	7.790	7.817	—.028	+.001
4.....	7.787	7.765	7.780	—.015	—.007

It is well known that cold rolling does not increase the Sp. Gr. of iron or of steel. To ascertain the effect of cold hammering under the

best conditions to increase Sp. Gr., viz.: by hammering between semi-circular dies, an experiment was made, the results of which are recorded in table IV.

A round bar, of carbon about 1.0 per cent., was operated upon.

The bar, as it came from the rolls and unannealed, was 0.682 in. diameter ; this is No. 1 in the table.

A piece of the same bar, annealed and pickled, was 0.673 in. diameter ; this is No. 2 in the table.

The same bar twice hammered cold, after annealing, was reduced to 0.624 in. diameter ; this is No. 3 in the table.

The same bar annealed, and hammered cold four times, was reduced to 0.564 in. diameter ; this is No. 4 in the table.

Prof. Langley first took the Sp. Gr. of the four pieces as he received them, 1 and 2 having the roll scale upon them, and 3 and 4 being bright polished, and slowly cooled. The results are given in column No. 1.

In this case No. 3 indicates an increase of Sp. Gr. due to the cold hammering. Prof. Langley then thinking that the results might have been affected by the scale in the first two pieces, removed the scale and boiled them all in weak potash, and upon removing them from the boiling liquid cooled them rapidly by plunging them quickly into cold water.

Column No. 2 gives the results, and here we have the remarkable fact that sudden cooling from boiling temperature causes a hardening effect, which is shown more particularly in Nos. 3 and 4, where there is a decided reduction of Sp. Gr.

If subsequent trials prove this deduction to be correct, it is very important. Desiring to fortify himself as to this matter of hardening at such a temperature, Prof. Langley again boiled the pieces and allowed them to cool very slowly, thus annealing them. The results are given in column No. 3.

Here is a progressive reduction of Sp. Gr., showing that cold hammering as well as cold rolling reduces Sp. Gr. The restoration of the Sp. Gr. of 3 and 4 to the results in column No. 1 shows that there was a hardening due to quenching from boiling temperature. The column of differences 3 and 2 shows the effect of hardening. The column of differences 3 and 1 shows the effect of removing the scale. This column also accounts for the increase of Sp. Gr. shown in the "restored," or annealed pieces of No. 1, table I., recorded in table III. The results recorded in table IV. have an im-

portant bearing on the inquiry into the cause of hardening, which will be shown later. They are also important as showing the entirely mercurial, or thermometric nature of steel. They also indicate a mode of accurate determination of the variable rate of change of volume in steels of different composition.

It will be remembered that there is such a variable rate of change clearly shown in table I., and further evidence will be given in table V.

Now by operating upon different samples by boiling, and sudden cooling in water of uniform temperature, we can get results which will range between certain uniform and known temperatures for each experiment.

TABLE V.

CHANGES IN VOLUME BY REPEATED HARDENING.

No. of times hardened.	No. 6 & 7, table I.C—about .848	No. 4, table I. C—.649.		No. 3, table I.C—.529	
	Contrac'n of hole	Expansion.	Contraction.	Expansion	Contrac'n
1	.00172	.....	.00257	.....	.00086
2	.00172	.....	.00086	.....	.00172
3	.00688	.....	.00482	.....	.00000
4	.00688	.....	.....	.00172	.....
5	.00688	.00172	.....	.00086	.....
6	.00000	.....	.00172	.00086	.....
7	.00344 cracked	not cracked.	.00000	notcrack'd	.00086
Total change.	.02752	.....	.00771	.00000	.00000

Hole was originally .75 diameter.

This is an experiment to find by measurement the effect of repeated hardening upon three pieces of steel containing different amounts of carbon.

A hole about .75 in. diameter was drilled in the middle of each piece. The measurements were taken by means of a tapered plug; the differences in the distance to which it entered in each case after the first and subsequent hardenings, were measured by micrometer. The left hand column gives the numbers of the successive hardenings. The other columns show the changes in the diameter of the

hole. The first piece, of carbon .848, showed contraction of the hole every time it was hardened except the sixth, and the piece cracked at the seventh hardening. The operator supposes the sixth hardening was accidentally omitted.

The second piece, of carbon .649, showed contraction three times, then no change; then an expansion of the hole followed by a contraction, and the seventh time there was no change. This piece did not crack.

The third piece, of carbon .529, showed two contractions, then no change, followed by three expansions, and seventh a contraction. This piece did not crack.

The total changes are quite marked, showing for carbon—

.848 = .02752 in.
.649 = .00771 in.
.529 = .00000

This shows in another way that steel of high carbon changes more in volume per degree of temperature, than steel of low carbon.

The high steel cracked, the low did not. All of the pieces were of the same quality.

The experiment recorded in table No. V. forms no part of the investigation by Prof. Langley and ourselves. It was made rather crudely for a practical purpose, and the results obtained in practice confirm the figures in the table.

This ends our record of facts and brings us to—

4. A statement of some of the theories which have been given as the cause of hardening.

Perhaps the oldest, one of the most plausible, and possibly the true reason, is that unhardened steel contains carbon in graphitic and uncombined form, and hardened steel has its carbon all combined.

For proof it is stated that when unhardened steel is dissolved, the insoluble residue contains flocculent graphitic carbon; and when hardened steel is dissolved it leaves no residue of carbon; therefore, the carbon has been combined in the hardening. To answer the objection to this, that it is impossible for iron and carbon to combine in all proportions, one writer states that there is formed a definite carbide Fe. C_4.

That this carbide is excessively hard and that it acts as a cement or glue, and therefore the high carbon steel becomes so much harder than the low carbon steel.

This will be conclusive after the carbide has been separated and thoroughly examined. Meantime, the hardening from boiling temperature is a little puzzling.

Another writer states that solution of the carbon takes place when the steel is heated, and that a great compression caused by sudden contraction in cooling is the cause of hardness.

If this be so, and our experiments are correct, then carbon dissolves in steel at the temperature of boiling water.

One writer hastens to inform us that steel hardens because part of the carbon is burnt out in heating, and the rest of the mass is compressed by the sudden cooling. It might afford amusement to demolish this theory, if it would not be a waste of time.

A steel maker of twenty years' practice, says hardening is caused by the carbon assuming the diamond form, in very minute crystals.

He gives as a proof, that the hot steel decomposes water, or the cooling mixture, which always contains hydrogen.

The hydrogen combines with the carbon to form diamonds, and this is proved by the fact that the diamond and hardened steel both refract light.

In case water is the cooling medium, the hydrogen penetrates the steel to form diamonds, while the freed oxygen, conveniently inert, stays on the outside to form a thin film of oxide.

As it is well known that mercury is one of the very best cooling liquids, giving extreme hardness to steel, it is necessary to this theory to show that mercury contains hydrogen.

Again, if steel really hardens upon being quenched from boiling temperature, then water must be decomposed by that temperature.

This diamond theory is very attractive and has received much consideration in our minds, but we are not prepared to consider it proven.

Another writer states that hardening is due to the sudden arresting of the molecular motion that exists in the heated steel, thus causing great tension and resulting hardness. He offers as proof, that hardened steel is weaker and more brittle than unhardened steel, and cites as a very happy illustration, the case of hardened glass, which is known to be in a high state of tension. This theory tallies with all of the facts better than any we have seen.

First, it covers all conditions, from the boiling temperature up to the high yellow heat which causes intense hardness and the brittleness of glass.

Again, it is certain that the higher the heat the greater the molecular motion. Also it is certain that from the highest heat we get the greatest hardness and the greatest brittleness.

Finally, the restoration of grain, and of Sp. Gr. by annealing, agree well with the idea of tension in one case, and the relief from tension in the other.

It is possible, even if this tension theory be accepted as correct, that there may be in connection with it, a change to diamond form, or from graphitic to combined carbon, and the formation of a definite carbide. Some one of these changes taking place at a given temperature, may be just what is needed to explain that very remarkable phenomenon known as "refining."

In mentioning a few practical considerations to be drawn from what has been said, it is hardly necessary to address the unfortunate smith and temperer; they, poor fellows, have heard so much of uniform heating and low heating, that they may well feel heartsick, and determined to do as they please anyhow.

Let them do as they will they will never be allowed to forget that same old cry—"too much heat"—"irregular heat," and so on.

Let that cry continue; it has its uses, and let us look at the engineer's side.

As steel advances with irresistible steps into the field of construction, the engineer naturally asks—

What am I to do with it?

Can it be worked safely?

Is it reliable?

Shall I use high steel or low?

How is it to be worked?

Is it safe to use the apparent advantages of great strength to be had in high steel?

Is it necessary to anneal finished work? etc., etc.

We think it has been clearly shown—

1. That a good soft heat is safe to use if steel be immediately and thoroughly worked.

It is a fact that good steel will endure more pounding than any iron.

2. If steel be left long in the fire it will lose its steely nature and grain, and partake of the nature of cast iron.

Steel should never be kept hot any longer than is necessary to the work to be done.

3. Steel is entirely mercurial under the action of heat, and a

careful study of the tables will show that there must of necessity be an injurious internal strain created, whenever two or more parts of the same piece are subjected to different temperatures.

4. It follows that when steel has been subjected to heat not absolutely uniform over the whole mass, careful annealing should be resorted to.

5. As the change of volume due to a degree of heat increases directly and rapidly with the quantity of carbon present, therefore high steel is more liable to dangerous internal strains than low steel, and great care should be exercised in the use of high steel.

6. Hot steel should always be put in a perfectly dry place of even temperature while cooling. A wet place in the floor might be sufficient to cause serious injury.

7. Never let any one fool you with the statement that his steel possesses a peculiar property which enables it to be "restored" after being "burned;" no more should you waste any money on nostrums for restoring burned steel.

We have shown how to restore "overheated" steel.

For "burned" steel, which is oxidized steel, there is only one way of restoration, and that is through the knobbling fire or the blast furnace.

"Overheating" and "restoring" should only be allowable for purposes of experiment. The process is one of disintegration and is always injurious.

8. Be careful not to overdo the annealing process; if carried too far it does great harm; and it is one of the commonest modes of destruction which the steel maker meets in his daily troubles.

It is hard to induce the average worker in steel to believe that very little annealing is necessary, and that a very little is really more efficacious than a great deal.

Finally, it is obvious that as steel is governed by certain and invariable laws in all of the changes mentioned, which laws are not yet as clearly defined as they should be, nor as they will be, nevertheless, the fact that there are such laws should give us confidence in the use of the material, because we may be sure of reaching reliable results by the proper observance of the laws; therefore there is no good reason why engineers should be afraid to use steel if they manipulate it intelligently. Now, if we have wandered over a wide range in answer to the simple question,—"Why Does Steel Harden?"—it was necessary to have looked at many facts before we could have

an intelligent opinion of many theories ; and if any are in doubt as to what is the correct answer to this momentous question, we can only say that we are all in the same boat, for if you do not know, neither do we.

DISCUSSION.

JAMES PARK, JR., of "The Black Diamond Steel Works," being called on, by the President, to open the discussion on Mr. Metcalf's paper, said : I regret another engagement for this evening prevented me from arriving in time to hear the reading of the paper from its commencement, but, having listened attentively to the closing pages, am sure the Society will feel encouraged in finding its first meeting opened under such favorable auspices.

I hail with pleasure such papers as the one we have just listened to, and thank its author and the firm with which he is connected, for the care and trouble taken in its preparation, and for the liberality incurred in making the extended experiments and investigations referred to in the paper.

We should feel under obligations to Mr. Metcalf for the interesting information imparted, as the line of experiments and investigations is new, and the publication of the paper will doubtless lead others to venture in the same direction, and extend their investigations, covering the various formulas relating to the manipulation of steel, such as the effects produced by heating, hardening, tempering, hot nicking, etc., etc.

My invariable rule, Mr. President, is to tell as little as possible of what I think I know in relation to cast steel, with the view of creating the impression that I know considerable, yet I may say, that the various characteristics, and what "the workmen" call "burning steel" are the most difficult problems I have ever encountered.

The steel maker of twenty years practice, to whom reference was made, and whose opinion is, that hardening is caused by carbon assuming the diamond form in very minute crystals, must have referred to "Black Diamond Steel." His theory, that the hydrogen combines with the carbon to form diamonds, and, that this is proved by the fact that the diamond and hardened steel both reflect light, may, so far as it relates to Black Diamond steel, be correct, because it has been found that those who purchase this brand accumulate

wealth "in its using," which is valuable as diamonds. Yet I am free to confess, that the light reflected from this steel, when hardened, is not sufficiently glaring to enable the observer to see the diamonds; but this may be accounted for by the crystals being so very minute.

While I do not propose to express an opinion in relation to the question, "Why Does Steel Harden?" I will quote Mr. Metcalf's "last words" in answer to this momentous question, "If you do not know, neither do we."

Sufficient care in heating, hardening and tempering cast steel is of greater importance than supposed by many who have charge of its manipulation.

It should be impressed upon all who superintend the heating, hardening and tempering of this important metal, that the element free oxygen, not the heat secured by the combination of oxygen and carbon, produces the many bad results which usually are blamed upon the steel.

With an experience of many years in the manufacture of cast steel, endeavoring to understand its peculiarities, and the danger it encounters, when in the hands of the workmen, I have listened to many theories, most of them from educated men, but the first time I was "hugely" gratified was some years ago, at the workshops of the Baltimore and Ohio Railroad Company, when the question was asked by one of the workmen in the smith shops, "Has not the *wind* a great deal to do with injuring steel?" That question came from a hard working, clear thinking man, without much "book knowledge." My answer was, "Yes, the wind, or blast, has *all* to do with it; the heat, but little or nothing." I was so greatly pleased with the intelligent question that my first inclination was to embrace that hard fisted workman; because, after years of "talks with workers of steel," on the subject of oxydizing the carbon of the steel, when heated, by allowing the free oxygen of the blast to come in contact with it, this man was the first I had been able to find whose intelligence prompted him to blame the *wind* and exonerate the heat and steel.

Mr. Jacob Reese said that he considered Mr. Metcalf's paper as one of the most important bearing upon hardening, tempering and annealing steel that he had ever listened to, and was especially pleased to know that after the important tests made that Mr. Metcalf favored the molecular theory. Prof. Tyndall has said:

"Temperature is the measure of molecular velocity as weight is the measure of ponderable matter." According to this theory the ultimate initial particles of matter are not in absolute impact, nor are they in an absolute state of rest at any time. The particles are endowed with two imponderable physical agents which are the prime factors of nearly all the physical and chemical phenomena exhibited in nature. It will be conceived that if the particles are held apart by these agents, there must exist certain cavities between adjacent particles. These cavities are known as physical pores. The atoms unite and form molecules ; the molecules unite and form the physical structure. Therefore there is an atomic physical pore, and a molecular physical pore.

I cannot account for the phenomena due to carbon in iron on the hypothesis of a chemical union, as the phenomena cannot be accounted for under the law of chemical equivalents. I believe that the carbon which is said to be chemically combined inhabits the atomic pores, and that the portion known as graphitic inhabits the molecular pores. As the physical pores are limited in area, so is the amount of carbon which the iron will take in limited. The atomic activity at a high temperature is so great as to cause the carbon to exude from the atomic to the molecular pores. And in cooling, the velocity is reduced so that the atomic pores again become saturated. The molecular resultant force of pure iron will only resist a tensile strain of 50,000 pounds to the square inch, but if we incorporate one per cent. of carbon with such iron it will resist 150,000 pounds tensile strain, and any modicum of one per cent. in proportion. If it be conceived that the force of attraction is much greater in carbon than in iron, it follows that the accompanying force of caloric must be greater, as these physical agents are always balanced. Now if there is a larger amount of the force of caloric accompanying carbon than accompanies iron, it follows that the molecular velocity of iron will be increased by the addition of every atom of carbon into the mass. And as increased velocity tends to separate the particles, the phenomenon of an increased expansion of steel with an increased amount of carbon, at any given temperature, is accounted for.

Mr. William Kent said that Mr. Metcalf had mentioned five different theories in regard to the hardening of steel, and Mr. Reese has given us the sixth. Another theory, which had occurred to the speaker some years ago while studying some phenomena of the

brittle alloys of copper and tin, but which he had never found time to develop, may possibly find a place with the other theories, and be left for the future consideration of students of molecular physics. It is that in all brittle materials the position of the molecules is such that lines joining them form the edges of a cube or other solid, whose sides are rectangles, while in ductile materials these lines form the edges of a tetrahedron or other solid whose sides are triangles : that is, the molecules are placed as cannon balls are usually piled, in which case a given number of them occupy a much smaller space than if the lines joining their centres formed rectangles. Applying this hypothesis to the hardening of steel, it may be supposed that in hardening steel the molecules take a relative position such that lines joining them approximately form rectangles, while in the soft steel the lines joining the centres approximately form triangles. The fact that hardened steel has a lower specific gravity than unhardened, that is that it occupies greater volume, would apparently tend to corroborate this theory. The speaker, however, did not wish to lay any great weight upon this theory, and believed that all theories of this sort have exceedingly small value as compared with the facts which may be handled by the practical man, and such facts as were given in Mr. Metcalf's paper. The facts concerning the specific gravity of hardened and unhardened steel which are given in the tables, will remain the data of reasoning, it may be for centuries, but the theories may all have to be abandoned as entirely worthless.

Mr. John L. Gill, Jr., gave an account of a curious incident which happened in his experience in hardening steel. A piece of high carbon tool steel, two and a half inches in diameter and ten inches long, was shaped into a knife edge for a testing machine, then carefully heated while enclosed in a gas pipe, and then tempered extremely hard. After being finished it was laid away upon a shelf for future use. Six weeks afterwards it broke in two with a report like a musket shot, and one piece was found five or six feet away from the other. No cause has been assigned for the sudden fracture.

James Park, Jr., said : I think, Mr. President, that the difficulty encountered by Mr. Gill was brought about by "too careful nursing." To avoid the effects of the blast, he "cradled" the piece of steel within the interior of a piece of gas pipe.

What was the condition of this pipe? How much oxide of iron did its interior surface contain? are pertinent questions. If the tube were or were not, hermetically sealed, and its inner surface were coated with oxide, the air in the tube would be sufficient to start an action between the carbon of the steel and the oxide, thereby transferring all the oxygen of the oxide to the carbon of the steel.

The reactions would go on during the heating of the steel, so carefully "cradled" in the oxidized tube, until all the oxide was reduced.

The extent of the action would depend on the amount of oxide in the tube. Even if oxide remained in the tube at the close of the heating operation it would not show that no action had taken place, since iron, reduced at a temperature too low for fusion, immediately oxidizes on the admission of air; we may therefore suppose the "gas pipe nursing" resulted in interfering and disturbing the chemical "relations" of the carbon of the steel, and, after giving the steel, thus provoked, a bath in cold water, heaping insult to injury, it took its own time, and then deliberately "went on a burst."

DESCRIPTION OF A DERRICK USED AT DAVIS ISLAND DAM.

By James H. Harlow, C. E.

[Read January 20, 1880.]

Nearly all the dimension stone used in the lock walls of the Davis Island Dam was received by rail from the Baden quarries, fifteen miles below the dam.

The dimension stone thus far received averages about one cubic yard to each block.

When the stone began to be delivered a double runner hand derrick was put up in the yard where the stone was deposited until needed in the walls.

A double derrick is one having two sets of falls, and machinery for working the same. At the foot of the mast on each side, and at right angles to the boom, the frame work is so arranged that a crank shaft and drum for working the fall lines can be placed upon it.

The crank shaft has on each end a crank for man power, and a pinion ; on the shaft is also an arrangement for holding the shaft in gear with the drum. Just back of the crank shaft and near the mast is the drum shaft, on each end of which is a spur wheel which gears into the pinion on the crank shaft. The crank shaft moves so that either or both of the pinions may be out of gear with the drum shaft.

The pinions on the crank shaft are so arranged that only one can be in gear with the drum shaft at the same time.

The spur wheel and its pinion on each end of the shafts are of different diameters, so that the speed can be increased when the weight to be lifted is decreased and vice versa.

The line running from the drum to the head of the mast, then to the end of the boom, and then through double and treble blocks, is called the "Fall."

The upper or double block on this line is fastened to the end of the boom.

The lower or treble block is movable, and rises or falls with the load.

Another line running from the drum to the head of the mast, thence through double and treble blocks, is called the "Runner."

The upper or double block is made fast at the head of the mast, or in order to save rope at the end of a single line, usually of wire, between the head of the mast and a point within the line of the boom.

This single line of wire must be of equal strength to the five it displaces.

The treble block on this line is fastened to the treble block of the fall and moves with it.

The boom is held in position in the usual manner by the boom fall, consisting of a double block fastened at the head of the mast and a double block made fast at the end of the boom, the end of the line being made fast over a cleat at the foot of the mast.

With a double derrick the boom is placed in the best position and allowed to remain, and the stone lifted within the limit of the boom by the "Fall" and "Runner" lines.

Supposing a stone to be lifted by the derrick, it can be moved out from the mast and on the same level by *lowering* the runner and *hoisting* the fall.

It may also be moved out from the mast and at the same time raised by *holding* the runner and *hoisting* the fall. By reversing this operation the stone is moved towards the mast.

Hoisting or lowering uniformly with both lines will raise or lower the stone vertically.

A derrick of the above description was first placed in the yard, but it could not be made to do the work required, although worked from 5 A. M. to 8 P. M., with a loss of about one-half hour for breakfast and one-half hour for dinner, making the actual working time about 14 hours per day.

As the delivery of stone was hindered by the inability to handle the stone in the yard, Lieut. Mahan in charge of the work, decided

to apply some power other than hand power to the derrick. Various plans were discussed and the one herein described was adopted.

The derrick was not changed except to take off the hand power and build a framing of oak which was bolted to the mast at right angles to the boom. On each of two opposite diagonal corners of this frame is bolted a small single engine. The cylinder of this engine is four inches in diameter and eight inches stroke. The engine is what is known as the "nigger reverse." The connecting rod of the engine is connected to the crank shaft, on which is a pinion with 22 teeth; this pinion gears into a spur wheel with 68 teeth on an idler shaft, which in turn by a pinion of 22 teeth is geared to the drum shaft by a spur wheel having 80 teeth.

On the crank shaft there is a small balance wheel, to assist the engine over its centers.

The pinion on the crank shaft is movable so as to be thrown out of gear and the engine allowed to run.

On one end of the drum shaft is a brake wheel to control the drum when disconnected with the engine or in lowering a stone.

The steam to run this derrick is taken from boilers situated about 250 feet from the derrick, through a pipe which passes up through the center of the mast to just below the platform upon which the engineer stands, and terminates in a T near the engineer.

On this T are placed two globe valves to act as throttles to control the steam to each engine.

At the foot of the mast there is a stuffing box through which the steam pipe passes, so that the derrick can turn without injuring the steam pipe.

One engine operates the runner, and the other the fall line. Within reach of the engineer, in addition to the two throttles, are two reverse levers, two brake levers, two shifting levers and two cylinder oil cups.

The mast for this derrick is 60 feet high, and the boom 70 feet long. The diameter of the circle reached by the derrick is about 125 feet.

The heaviest stone handled contained about 93 cubic feet, and would weigh about 6 tons.

The derrick was always able to handle any stone required, but it would have been better had the cylinders been a little larger.

While the derrick was being worked by hand no accurate account was kept of the number of lifts made, but the man in charge of

this derrick thinks, with everything favorable, he could make about 60 lifts in 10 hours, including the lifts made for the stone cutters within reach of derrick.

The derrick as run by steam will make about 150 lifts in 10 hours under the same conditions.

As shown above, the hand derrick would make a lift in 0.167 day, while the steam derrick would make a lift in 0.067 day.

The force to run the hand derrick consisted on the average of 1 foreman, (who also dogged the stone), 1 tagman, 4 laborers at the derrick, one or more of whom acted as assistant tagmen after the stone was lifted. A total of 6 men.

The steam derrick under the same conditions required 1 foreman, 1 engineer, 2 tagmen. A total of 4 men.

If we assume the pay of the foreman and engineer to be $2 each per day and the others $1.50 each per day, the cost per lift *in dollars* by hand is 0.167; by steam is 0.047.

In this estimate no account is taken of the cost of the derrick, machinery, repairs or steam.

The cost per lift *in days work* by hand is 0.100 ; by steam 0.026.

The amount of useful work done by the use of steam as compared to hand power is : In stone handled, 2.50 times ; per day labor expended, 3.85 times ; per dollar expended, 3.56 times.

THE ALLEGHENY RIVER.

By T. P. Roberts, C. E.

[Read February 17, 1880.]

Observation of a number of rivers in this country confirms me in the belief that no two of them are alike ; each one has its own peculiarities. The causes conspiring to produce this diversity are numerous, for, aside from comparative differences due to volume and slope, they are affected by the geological structure, the topography, the climate, and the flora of the diverse regions through which they flow. We cannot, therefore, wonder at the lack of harmony in the natural regimen of different rivers.

The study of the individual features of a river should properly precede the proposed application of any system of improvement. Many emigrants from the Eastern States were, in early times, drowned in attempting to ford the Platte river, Nebraska, because, as it was only three feet to the bottom, they thought, of course, it was fordable, like the "old Juniata" at home. Unfortunately the drivers of those teams went into the investigation of quicksand bottoms at too late a period in life to see the result of their labors published.

I will, therefore, before speaking of what may be proposed for the improvement of the Allegheny river, refer to some of its prominent features, so that members of the Society can the better judge not only as to the practicability of proposed plans, but also as to *advisability* of its improvement.

The name Allegheny, spelled A-L-L-E-G-A-N-Y and A-L-L-E-G-H-A-N-Y in New York, is derived from the dialect of the Seneca tribe of In-

dians, a remnant of whom are still living on the headwaters of the river. The word "Allegheny" signifies "fair water." As the Indian word "Ohio," in other dialects, also means "fair water," it is thought that the one was merely the translation of the other, and that the aborigines considered the two rivers to be, as in fact they are, one and the same stream. Were it not for the change of name at Pittsburgh, the Ohio, instead of being stated as it frequently is in tables as a river 967 miles long, would be properly given as 1292 miles—the Allegheny adding 325 miles to its length.

SOURCE, AREA OF VALLEY, ETC.

The Allegheny heads in Potter county, Pa., interlocking with the headwaters of the Susquehanna and Genesee rivers. It is said that rivulets in that county, from a spot less than one square mile area, discharge their waters respectively into streams flowing to the Chesapeake Bay, the Gulf of St. Lawrence and the Gulf of Mexico.

The area of the basin of the Allegheny is about 13,000 square miles, making at Pittsburgh very nearly two-thirds of the total area drained by the Ohio at this point. A glance at diagram marked No. 1 shows the arrangement of the principal tributaries of both the Monongahela and the Allegheny rivers. It will be seen that we have blended at this city waters from New York, West Virginia and Maryland with that from Pennsylvania.

While the entire basin is embraced within four degrees of latitude, there is probably no similar area in the country marked by such diversities of climate, particularly of the winter season. The greater severity of the winters on the upper Allegheny, as compared with the same season on the upper Monongahela, is due to several causes, among which may be mentioned that whereas the former occupies a very much more elevated region than the latter, it is also subject to the climatic influence of Lake Erie, which permits the bleak northwest winds to reach it unbroken in force and but little modified in temperature. The further we ascend the Monongahela the milder the climate becomes and the less is it subject to freezing. Ice gorges, particularly above Morgantown, are seldom seen upon it. I made surveys on that portion of the stream for slackwater purposes in 1875, and was assured by the "oldest inhabitant," that he never heard of damages to the banks, trees or buildings, or an overflow of the banks being caused by an ice gorge. While, on the other hand, the Allegheny river is without doubt

more subject to hard freezing and ice gorges than any river between the Allegheny Mountains and the Missouri. As this is one of its marked difficulties I will refer to the causes and effects of its ice gorges more particularly hereafter.

I will call your attention to the fact, which can be seen on Chart No. 1, that the Allegheny from its headwaters flows a number of miles northwardly from Potter county, as though it had originally some intention of falling into Lake Ontario, but changed its mind, and after passing eastwardly to Salamanca, had concluded to come down to Pittsburgh and join the Mississippi system of rivers. I am of the opinion that its upper waters were once contributed to the St. Lawrence system. Even yet, its prism at Olean, seventy miles below its extreme source, is only sixty-seven feet below the divide separating it from the waters of the Genesee. In other words, a dam 67 feet high across its valley at Olean would cause it now to discharge its waters into Lake Ontario. When the late Mr. Chas. Ellet, the distinguished civil engineer, many years ago proposed to improve the navigation of the Ohio by means of immense reservoirs on the headwaters of this and other tributaries of that stream with dams 100 feet high, he was certainly not aware of this interesting fact concerning the Allegheny. It is chiefly worthy of mention now in view of any proposed canal connection between the Allegheny and the New York canal system. I will mention further, that a canal from Olean to Rochester is already in existence, though recently abandoned for want of a business connection at the Allegheny. That canal could easily be enlarged and put in order in case the Allegheny river was improved that far up.

PROFILE, FLOODS, BOTTOM LANDS, ETC.

It is a somewhat singular circumstance that for a considerable distance the headwaters of the Allegheny have a less fall per mile than the main portion further down. For 25 miles above Olean it is stated to have a descent averaging considerably less than two feet per mile. As a steamer from Pittsburgh once ascended to Olean—proving there were no serious natural obstacles on 255 miles of its course—there is but little doubt that even at ordinary freshet stages the same boat, or a much larger one, could have approached to within less than 50 miles of the initial spring which gives birth to the Allegheny river. This feat, we believe, would have been without a possible parallel on any other unimproved river in America.

Below Olean, in the first 20 miles, our levels show that its descent is at the rate of 1.7 feet per mile. In this comparatively flat portion of its course, the river flows through extensive bottoms, measuring in places a mile or more wide on both sides to the foot hills. These bottoms are in part subject to overflow, even with a rise of ten to twelve feet, which, if effecting no material damage to property, as such places remain uncultivated, the water at least fills up the sloughs and makes impassable morasses. The high water of 1873 rose 15.8 feet at Olean, or about six feet higher than the ordinary banks of the river. Some portions, however, of these bottoms rise in terraces above the flood lines and are under a high state of cultivation.

This portion of the Allegheny valley is radically different from the country below. In fact it has no characteristics common with the river between Pittsburgh and Warren. It might be compared with the Mississippi river between St. Paul and Lake Pepin, or in another important respect, with the same river below Cairo, as in time levees will be suggested to protect its borders from overflow. No rocks or boulders appear in the bed of the stream, the bottom being composed of a fine gravel or sand, whereas the river, for nearly 200 miles above Pittsburgh, has a coarse gravel, boulder and rocky bottom, and only a limited extent of bottom land. It is possible that a shallow lake, similar in some respects to the adjoining long, narrow lakes in New York, once occupied this part of the main valley, with its outlet into the Genesee, but which, by a general subsidence of the country in a southerly direction, was drained out. The fact that Conneaut Lake, which naturally drains into the Allegheny river through French creek, was, by the construction of a dam of moderate height, made to turn back in its course and feed a canal with its discharge into Lake Erie, in a measure supports the evidence of the former existence of a similar lake here. The valuable and interesting reports of Gen. G. K. Warren have invested with much interest his hypothesis of a continental subsidence to the northward of a line passing through northwestern Minnesota, Wisconsin, and thence southward of Lake Erie to the head of the Maumee, where his investigations stopped. At the last mentioned point I am satisfied, after a personal examination, a lake existed which has been drained off northwardly, though there is evidence here that the line or axis of movement was marked by a local subsidence in an opposite direction. The main valley of

the Connewango river, entering the Allegheny 67 miles below Olean at Warren, also presents topographical features indicative of lacustrine origin.

There is a sudden change in the profile of the river near Salamanca, 23 miles below Olean ; the second twenty mile section, descending at the rate of 3.7 feet per mile, increasing to five feet per mile in the third twenty miles, but decreasing in the fourth twenty mile division to 3.5 feet per mile. The average descent of the river between Olean and Franklin, 132 miles, is 3.4 feet per mile. Between Olean and Pittsburgh, 255 miles, the descent is 2.8 feet per mile, the total fall being 708 feet, Olean being as much above Pittsburgh as Pittsburgh is above the level of the ocean.

At the seventy-third mile the hills finally converge on the river bank, and from thence to the mouth of the Mahoning, 127 miles, follow the river quite closely, leaving only occasionally any bottom land, the exceptions being at the mouths of large tributaries. The absence of bottom lands for such a long distance is a striking feature of this river.

CHARACTER OF BED, ICE GORGES, ETC.

From what has been said concerning the differences existing in the different portions of the valley of the Allegheny, it is natural to expect that the river itself would not have the same regimen throughout its course, and it certainly has not. Below Olean the river, 300 feet wide, meanders through its wide valley with a fine sandy bottom to Jamison's, 27½ miles. Here a few rocks and small boulders make their appearance for the first time in the bed of the stream, though for 35 miles more it still retains in general a soft bottom, the most noticeable exception being met with at Limestone Falls, 47½ miles below Olean. There is here a solid ledge of limestone underlying the river bed, the descent being 3.84 feet in 650 feet. Throughout the first 60 miles the pools intervening between rapids are shallow, rarely exceeding five feet depth at low water. After receiving the Connewango at Warren, the river at ordinary stages is 500 feet wide, the pools thence to Oil City varying from 6 to 10 feet or more in depth, and the rocks which have fallen down from the hills, or which have been pushed out by the tributaries when in high flood, gradually increase in number and size in the channel. From Tionesta, 105 miles below Olean, thence to Pittsburgh, rocks are seldom absent from the shoals, often lying partly

buried up in the gravel, and proving dangerous obstructions to the navigation. From below Franklin the pools gradually deepen to 14 feet or over, and average about a mile in length. Some of the pools are 25 and more feet deep at the very lowest stage. Unlike some other rivers, the low water discharge of the Allegheny is not sufficient to maintain a regular slope due to its fall of over two feet to the mile. At such periods its pools are practically level, and the river really descends a "stairway" with 265 steps in it, between Olean and Pittsburgh. Seventy-five of these "steps," rapids, ripples, or shoals, as they are alternately termed, occur between this city and Franklin, 123 miles. The remaining ripples are found in the 132 miles above Franklin to Olean.

As our river news editors failed to understand how it came last summer that they could establish no marks in the pool here which would correctly record the depth on the shoals below, I have constructed a diagram, marked No. 7, which will aid in explaining the so-called phenomenon, or difficulty, they labored under. The matter, I believe, was never explained before. It is known that water in discharging over any weir increases in velocity with every increase of depth or volume, but I have seen no reference to the fact that the water will not for a time rise as fast, or fall as fast, as the case may be, on the weir with an increase of discharge, as it will at the upper end of the pool above it. The cause is this, viz: That the vastly greater velocity at the weir, as the water rises, enables it to discharge more water with a less increase of sectional area than would be required in the slower moving pool. Hence, starting with a level pool, the marks placed near its head may at the intermediate stages, below the depth above which the river assumes its regular inclination, differ a number of inches from a gauge at the ripple. A grand illustration of this fact is to be seen at the falls of the Ohio at Louisville. I have witnessed a flood there which at Cincinnati, 132 miles above, registered 41 feet in height, while on the crest of the falls the depth, with about the same quantity of water passing, was only 26 feet; yet immediately below the falls the original depth of 41 feet was registered. At this rate a flood of 80 feet would leave no falls at all at Louisville. Still some opponents of slack water, and who should know better, persist in affirming that dams of six feet lift on the Ohio will increase the height of floods to the extent of their lift. The simplest way of silencing these antiquated people would probably be to have them see the

Monongahela at a flood stage, and ask them to point out the position of Dam No. 1. They would see at that place only swirls in the current due to the water traveling faster than elsewhere, but no appreciable fall or change of slope.

TRAVELING BOULDERS, ETC.

The waters of the Allegheny are naturally so clear that I have frequently seen the bottom where it was 16 feet deep. The beds of the lower river pools are sometimes composed of large, irregular fragments of rock, varying from less than one to twenty cubic yards or more in capacity. I was surprised, on looking down carefully into the deep pools, to observe that so little small stone or gravel occupied the cavernous spaces between the rocks. As such pools sometimes occur between shores which are rocky, or solid, the query arose as to how the large, and sometimes shifting gravel and boulder bars at their lower ends were maintained—not only maintained, but occasionally observed to be enlarging in area and height. Certain velocities will doubtless enable a stream to carry in suspension certain sized particles of sand, gravel, etc., but I can scarcely conceive that boulders five, six and ten inches in diameter, and occasionally rocks of a ton's weight, or more (for these also have been noticed to change from place to place), are transported by the current over these deep pools. We should expect some of them, on the theory of "suspension," to be caught by the bottom eddies and thrown down into the deep receptacles between the rocks referred to. Neither is it easy to conceive that such materials could have been rolled or pushed along over such an irregular bottom. We must, however, recognize the fact that these boulders and rocks *do* travel, year by year, down the streams. The boulders left at the glacial period, which is believed by some geologists to have extended on the meridian of the Allegheny no further south than Oil City or Franklin, can now be found in the bars of the Ohio as far south as Louisville.

I venture to offer the following explanation of their movement, which, as it is another of the marked characteristics of the Allegheny, should be understood.

As before said, the Allegheny is remarkably subject to hard freezing, ice gorges, etc. Clear ice, thirty inches thick, forms sometimes in the neighborhood of Franklin and above. It freezes so heavily and becomes so fast to the shores that it will not float

with a rise, sometimes allowing *four feet* of water to flow freely over it—a depth sufficient for the navigation of large steamboats, forming a combined skating and swimming park. In the break up, which may happen several times during one winter, the ice no sooner gets in motion than gorges will form at some of the shoals, or in the narrow bends. The motion once checked, the ice soon piles up in a "pell mell," decidedly reckless manner, until a partial, or sometimes perfect dam, is formed, raising the water many feet and forcing the ice high up on the banks. Eventually the gorge moves, though it sometimes happens that colder weather will set in before it starts, in which case immense masses of the stranded ice, piled on the bars and along the shores, remain behind. These latter soon become solid, holding in their embrace the boulders, gravel, detached rocks, and even full-grown living trees whose roots may have become enveloped by the ice. Finally a flood of sufficient depth arrives when these miniature icebergs, often drawing ten feet of water, find themselves in the stream. Being, as I have supposed, weighted with stone below their centre of gravity, they will not turn, but float over the deep pools, parting with their freight only by attrition with the river's bed on the shoals. Hence the growth of these bars.

The extremely cold winter climate of the elevated regions about its headwaters, its rapid descent causing great velocity of the current, the suddenness of its floods, and the number of its short bends, conspire in the Allegheny to make the troubles from ice an important factor to be taken into consideration by the engineer in preparing plans for its improvement. Reliable accounts in detail of its ice gorges changing the channels, washing away bars and islands, and occasionally rebuilding others in their stead, are difficult to obtain, although the marks of their action are everywhere visible along the river as plain as the track of the lightning on the blasted oak.

CASES CITED.

At Jamison's Falls, 27½ miles below Olean, an ice gorge formed a few years ago, closing the river. It made such a dam that it caused the river to overflow to the right. The water then took a westerly course across the bottom, washing away trees, etc., and falling into a run near its mouth, so found its way back to the river, a mile below the gorge. Had the flow continued a few days longer it would

undoubtedly have made a large island. At all events, it is only a question of probabilities when another gorge will form in the same place, which, when it occurs, will divide the channel and finish the construction of the half-made island.

A not uncommon occurrence on the Allegheny river is an island cut in two. Lower Cornplanter Island, 51 miles below Olean, was, prior to 1865, over a mile in length, but a gorge closed its right hand chute, about midway down, and very likely the left chute also, higher up. At all events, the water broke through, over and across near the middle of the island, cutting it down to below the surface of the lowest water, and with the usual effect of leaving extensive bars to impede the channel below where it first stopped. I have purposely added a half mile of river to this rough sketch, in order to show the fiftieth mile point below Olean, where a monument was erected by the State of Pennsylvania to mark the grave of Cornplanter, the celebrated chief of the Senecas, who died about 1823, at the age of over 100 years. Several islands and creeks bear his name, and it was also a favorite name for Allegheny river steamboats.

No. 5 represents a case similar to the last, on the Missouri, 30 miles below the mouth of the Yellowstone, which fell under my notice in making a reconnoissance of that river in 1872. The scale of this diagram is made smaller than the others—the river being a vastly larger stream than the Allegheny. The channel, in 1869, was through A to B, and the mouth of the Big Muddy was then over three miles below its position in 1872. The Sioux, or the Gros Venture Indians, were the only possible witnesses to the occurrence—but it is probable that a gorge formed at A—and the water overflowed the banks to the left, until it fell into the course of the Big Muddy, which it immediately proceeded to repair and enlarge, as became the size of the new tenant. The Missouri, unlike the Allegheny, never hesitates what course to pursue when impeded in any manner; it takes the lowest grade route, and holds it until it has obtained all the elbow room it wants, though never long contented in one position. It truly is a reckless, wayward, impulsive, spoiled river.

There is a peculiarity which I have not seen or heard of in any other river beside the Allegheny in the alluvial portion of the Mississipi valley, and this is in regard to its frequent exceptions to the rule of the best channel following in the bends. If the water in a

river is free to act it will be found that the gravitation of the greatest volume is into the bend, and there also will be found the greatest velocity; while the decreased velocity on the point side causes the precipitation of matter held in suspension, and consequently a bar off that side is formed. A company of soldiers turning by the "right wheel" will illustrate the case in point, the men on the left flank of each platoon having to encompass a greater distance in equal time than those nearer the post or right end man. Yet on the Allegheny at a number of places, such, for instance, as at the mouth of the Mahoning, the low water channel will be seen straggling across the point, often amid scattered rocks, while the other, or bend side of the river, will present a large area of dry gravel bars. I was at a loss to account for this anomalous action of the river until I happened to think that it might be due to the action of ice gorges, which, jamming into the bends with great violence in times of freshets, would first break through at the weaker ends of the ice dam. The pent up waters thence having an outlet across the points would soon cut out a deep channel into which the low water would draw, notwithstanding the rocks which impeded it.

A LOCAL SINGULARITY.

I shall next speak of the formation of an ice gorge, due to a somewhat exceptional cause, and which happened within the limits of this city on the Allegheny river, opposite Fiftieth street, nearly five miles above the Point. Fiftieth street prior to the winter of 1876-7 abutted about midway on the pool, two miles long, between Six Mile and Herr's Island. This pool was from 1000 to 1100 feet wide, the normal width of the lower part of the river, and in 1868, when I happened to have sounded it, was from six to sixteen feet deep, and generally over ten feet depth. The pool, as can be seen, is somewhat bowed or crescent shaped, on an arc of great radius, which, for purposes of navigation, may be considered straight river, and no serious shore projections interfered with its free flow or discharge at any time. My attention was called to this place last fall because a large bar had formed in the river opposite Fiftieth street, which prior to the winter mentioned had no existence. The place presented none of the prime conditions requisite to cause a gorge, viz., contraction of section either by shoalness or narrowness, and no gorge, I am informed, had stopped there before. In looking up the river record, and from the information of river men, I

learned that the disastrous ice flood on the Monongahela in that winter caused a flood of over 20 feet in that river. This was on January 16th, 1877. On that day also, the Kiskiminitas river broke up and started the ice in the Allegheny for thirty miles down, but it was running at an uncommonly low stage, viz., about 5½ feet depth. This Allegheny and Kiskiminitas ice, therefore, when it encountered the back water from the Monongahela flood had its velocity retarded owing to the great increase of section, and being unable to go ahead fast enough the forward cakes were rapidly overtaken by those following, borne down to the bottom, and thence the gorge began to pile up until it made a dam 25 feet high, or from its base 41 feet high, overflowing the bottoms and covering them with ice. The gorge was about 10 miles in length, and I would estimate contained 25,000,000 tons of ice. It remained intact over two weeks, during which period it partially melted, but before giving way the great pressure of the water began to undermine the bottom, near its foot, in its efforts to make outlets. The scour extended up as far as the Sharpsburg bridge. The material removed was deposited in the form of the bar mentioned, below the gorge at Fiftieth street, which now shows itself dry out of water at the lowest stage, and where before the water was sixteen feet deep. The area of this bar to the base is about eight acres, and it contains about 125,000 cubic yards. A head of twenty-five feet is ample, in my opinion, to wash out beneath ice gorges any gravel or small stone which come in the track of its force. As this gorge greatly deepened the water below the Sharpsburg bridge, where formerly there was a ford, I am inclined to think, reasoning therefrom, that all the deep, rocky bottomed pools in the Allegheny—now so free of gravel, were made so by a similar process. We must believe, therefore, on this hypothesis, that the shoals on this river are liable to be shifted and their places occupied sometimes by pools. A careful study of the profile of the river, in connection with its thalweg, I believe will demonstrate that these inferences are well founded.

Such being some of the actual and possible effects produced by the almost irresistible power of ice gorges on this river, the engineer in proposing plans for its radical improvement by means of adjustable dams with locks or chutes—which must come in some shape in the future—will be called upon to provide extraordinary means for their security and for the permanent maintenance of a navigable depth in their pools.

The chief problem, in my opinion, will be the remedy to apply to break up this bad habit the river has of periodically choking up with ice. We must meet this or run an imminent risk of having our costly works destroyed. Indeed I think it probable that soon after the completion of the Davis Island Dam something of this sort will have to be attempted on the Allegheny river in order to make the harbor of Pittsburgh safe in winter for the thousands of boats and barges that will constantly occupy it.

The lowering of several adjustable dams which might be arranged for the purpose at various points on the main stream and upon the principal tributaries, would create such undulations or pond freshets as to prevent, I think, the ice from ever becoming dangerous.

An evil in the way of any improvement of this river is the number of low bridges which this Commonwealth and the State of New York have allowed to be constructed. Between this city and Olean there are 32 of these bridges, several of which have their lower chords within a foot or two of the highest water surface, and one or two of them have those members actually below the high water line. In every case, however, above the limits of this city, no one would probably object to having them raised in order to accommodate an improved navigation.

THE COMMERCE OF THE ALLEGHENY RIVER.

It would occupy much time to give the details of the trade of this river, and besides, also, no reliable records can be obtained in regard either to the quantity or the value of the commodities transported upon it. I will say briefly that even in its present primeval state, with dangerous rocks abounding at every rapid, that it floats a commerce of no mean proportion. There are a number of steamers regularly engaged in transporting oil from the oil regions to this city and to points on the Ohio. This oil is carried in bulk boats, and three of them, with a towboat, make an Allegheny fleet. An average tow will be about 7500 barrels. The total amount annually transported is over 300,000 barrels. About 200,000,000 feet B. M. of pine lumber is annually floated down the river, and a very large business is also done in the transportation of limestone, building stone, staves and barrels; also boulders for street paving purposes. The aggregate value of the articles shipped on the river will, I feel satisfied, considerably exceed $5,000,000. But

it is wrong to assume that because only this amount is done, in say, four months of the year, that a perennial navigation would at the best only aggregate $15,000,000; because so great are the uncertainties of the time of navigation that shippers cannot be prepared for them always. Nor is it to be expected that capital in boats will be largely invested under such circumstances. No matter how deep the water may be occasionally, there can be no successful competition between river and rail as long as the trips of the boats are too infrequent to pay a legitimate interest on the cost of investment.

THE IMPROVEMENT OF THE ALLEGHENY.

The plan for the immediate improvement of the Allegheny which has been approved by Col. Wm. E. Merrill, U. S. Corps of Engineers, who has general charge of this river, is a system of low wing dams to confine the water at the shoals, and includes also the removal of rocks, etc.

Very often the rapids are navigable at low stages for small boats which can avoid the rocks. But for a steamer drawing two feet, three feet depth is required to make its navigation safe. Now it is just that particular foot, viz., the foot between the two and the three feet stage, in which the river delights to fluctuate for many weeks, aggregating months in the year, in a manner extremely tantalizing to the owners of steamboats. I believe, therefore, in calling the removal of the rocks an improvement of one foot depth to the navigation. The wing dams, by the increase of several inches depth at the lowest stage, and over a foot of real increase in middling stages, further retards the decline of the river below a two-foot depth. Some interesting questions arise even in this simple kind of improvement in connection with the location of the dams with reference to the current, choice of channels to be closed, etc. As this species of improvement extends the field of river commerce, the Government will no doubt enlarge its facilities by means of a more radical improvement.

I had thought, when I started out, as I said, to refer at some length to the *advisability* of the improvement of this river and to speak of some of the more radical means which have been proposed, and particularly of the Du Bois system, which has lately been agitated and indorsed in the Chamber of Commerce. But if the probability of getting the Government to immediately start

with a radical improvement of the Allegheny is remote, we might as well discuss the question of railroads in the lunar mountains for the purpose of transporting the precious ores believed to exist in the "silvery orb" to our smelters. But I understand Mr. Du Bois proposes merely to build one of his locks and dams, more especially for the benefit of the city harbor in the Allegheny. He proposes, further, to build this with his own means, and guarantee its successful operation, after which the Government is to remunerate him.

Mr. Du Bois' plan of lock gate is precisely in principle the old original bear trap gate which my father, "when a boy," saw in use in the Lehigh river. It is known that it will work in chutes of moderate width, but as to making it serviceable as the feature in an adjustable dam, there is ground for the belief that the irregularity of settlement in the dam, and its own warping, will prevent its free play. It might, however, be worked in sections. There are other automatic gates preferable, in my opinion, to Mr. Du Bois'.

A novelty in dam construction is, however, proposed by Mr. Du Bois, namely, to erect his dam immediately on the gravel. He believes that by flooring the bottom of his cribs and sinking them in line across the river, with sharp edged lips beneath, protruding a few inches into the gravel, that percolation will proceed so slowly as never to create any scour or undermining. He claims that he built a dam on this plan some years ago on Lycoming creek, in this State, where others dependent upon sheet piling to prevent leakage failed, and that his own is still standing. I cannot as yet comprehend this idea of Mr. Du Bois'. If it is true, engineers have been squandering money on subaqueous foundations for several thousand years. I can see no difference between the gravel under his dam as a preventive of leaks, and that which is so often placed above other dams over a much greater width of river bottom than the floor of his dam, and which has yet not prevented undermining and the washing away of the structures. He is right in his idea of "keeping" the gravel under his dam, and I think it often would be well to sheet-pile the toe of the aprons as well as the edge of the up stream slope; but before placing much dependence on surface gravel foundations, exposed as it would be under his dam, to a hydrostatic pressure of 10 lbs. to the square inch, I would advise him to cement it with grout, forced into its mass for several feet deep by means of pumps. But this would be a beton—not a gravel foundation. Still, as a friend to experiments I would be glad to see Mr. Du Bois

start work on the Allegheny, and I wish him every success. But as it may be some years before any work is undertaken far above Pittsburgh for a radical improvement of navigation, I will close this paper with a recital of the estimate I recently made for the low water improvement of the river to Warren, 188 miles above Pittsburgh.

PITTSBURGH TO BRADY'S BEND, 69 MILES.

The improvement of this division would enable the oil boats to reach the lower, or Butler oil field, and would be of the first importance to the limestone trade, which gives employment to 500 hands. It would also enable the rafts from the Kiskiminitas, the Red Bank and the Mahoning river to descend with safety at the lowest stages in which they can float. For this division there would be required:

To finish the two dams begun in 1879	$ 4,000
Twelve new wing dams, at $3,500 each	42,000
For the removal of rocks, etc	7,000
Total	$53,000

BRADY'S BEND TO OIL CITY, 61 MILES.

This division reaches to the middle oil fields, and its improvement would be of benefit to the populous towns of Parker City, Emlenton, Franklin and Oil City. It would also develop a large coal trade and enlarge the stave and lumber business from the valleys of Clarion river, French creek, etc. For this division I would estimate as follows:

Ten wing dams, at $2,500 each	$25,000
Removal of rocks, etc	3,000
Total	$28,000

THIRD DIVISION (OIL CITY TO WARREN), 58 MILES.

The improvement of this division would be of great benefit to the lumbermen and an advantage to the thriving towns of Tionesta,

Tidioute and Warren. It would reach the great industry in hemlock bark, an article now extensively used for tanning purposes. For this division I would estimate as follows:

Nineteen wing dams, at $1,500 each	$28,500
Removal of rocks, etc	2,000
Total	$30,500

The total for the improvement of 188 miles of river, allowing 10 per cent. for contingencies and engineering, and including $10,000 already expended, amounts to $133,650, which makes an average of less than $700 per mile, not greatly exceeding the cost of a first-class telegraph line for the same distance. The cost of this work as here estimated, is less than the cost of constructing one dam with a lock, which would pond the water only five miles.

THE METRIC SYSTEM.

By Wm. Kent, M. E.

[Read March 20, 1880.]

Every society of engineers must, at some period of its existence, endure the infliction of a paper on the Metric System, with perhaps an almost interminable discussion on the subject. The result of the paper and the discussion is usually to advance the sum of human knowledge only in the most infinitesimal degree, and to leave every participant and every hearer only confirmed in his original opinion, just as if the discussion were upon religion, politics, or political economy. In view of these facts my presumption in taking upon myself the task of inflicting the paper should be worthy of condemnation; but I plead as my excuse that the task was laid upon me by our estimable President, who had made up his mind that some one should start the discussion, and he selected one of the members whom he thought he could most easily influence.

In this paper no attempt will be made to cover the whole ground of the argument either for or against the metric system. A few salient points of the arguments on both sides will merely be touched upon, and one or two private opinions of the writer ventilated, and then the subject will be left to the mercy of its champions or opponents among our members.

In the first place, the intrinsic merits of the metric system of weights and measures are unquestionable. A compact, uniform system, based upon a single standard unit of length, with decimal divisions only, it has all the advantages of simplicity, convenience

of calculation, and adaptability that any possible system could have. It is as far in advance of our present multiform systems of weights and measures as our decimal money system, dollars and cents, is ahead of the English barbarism of pounds, shillings, pence and farthings. If the simple merits of the English and the French weights and measures, therefore, are to be compared, no thinking mind would hesitate in giving preference to the latter. It is only upon the question of the practicability and the advisability of substituting an unfamiliar, although superior system, for the one which has long been ingrafted into our very life, that the opinions of men differ. As is usual in disputed questions, there is much that may be said with reason upon both sides, and there is much that is said that savors of the bias of prejudice and the heat of passion.

To show how people will differ upon this subject, two opinions may here be given. The first is by an editorial writer in an engineering periodical: "They (the metric measures) are now adopted by nearly every civilized country, and it is too late to-day to tell any intelligent being that they are not infinitely superior in every respect to the very nightmare of weights and measures which has come down to us from the barbarism of the middle ages, and which nothing but ignorance of the other system could make any one desire to perpetuate."

The other is from an official letter of Quartermaster General Meigs, U. S. A. "The fact is that the meter is quite as arbitrary and unscientific a standard as the foot or yard. It is of less convenient length than either of them, and its compulsory adoption would derange the titles and records of every farm and of every city and village lot in the United States; would put every merchant, farmer, manufacturer and mechanic to an unnecessary expense and trouble, and all, it seems to me, for the sake of indulging a fancy only, and a baseless fancy, of closet philosophers and mathematicians for a scientific basis of measures and weights, which (as the meter is not a ten millionth part of the Paris quadrant, is not what it professes to be,) cannot be found in the French system."

The chief advantages claimed for the metric system, may be briefly summarized as follows :

1. The meter, upon which the whole system is based, is a single fixed and invariable standard.

2. The system has been adopted by nearly all civilized nations.

3. The small number of terms or measuring units necessary to express every conceivable dimension, weight or volume.

4. The decimal division of the units, with the consequent facility of making all calculations.

The chief objections made to its introduction in the United States are :

1. The English system has some advantages which the French has not, such as that of indefinite binary division, into halves, quarters, etc.

2. The English system is not so bad as the advocates of the French system claim. Its incongruities are harmless, and its inconveniences more imaginary than real.

3. While the French system has been adopted by the majority of civilized countries, it has not been adopted by those countries with which the United States has the largest commercial dealings, viz., the countries whose people speak the English language. The advantage of our being in accord with the continent of Europe in our system of weights and measures would be more than balanced by our not being in accord with England alone.

4. The great difficulty of familiarizing our people with the new units, and more especially with the convenient use of them.

5. The confusion which would ensue in all branches of industry in which gauges, parts of machines, buildings, etc., are made in sizes measured by the foot and inch, and in records of land measured by the English land measures, together with the vast expense incurred in changing every scale, every weight, every yardstick and two-foot rule. The cost of metric scales and balances to take the place of those now used by the United States Post Office Department alone has been estimated at $125,000.

Conceding the intrinsic superiority of the metric system of weights and measures over every other, let us consider some of the difficulties of its introduction.

First. The great difficulty in familiarizing our people with the new system. Mr. C. P. Patterson, Superintendent of the United States Coast Survey, says: 'This subject has been a matter of thought to myself for several years, and the more I have heard it discussed the more convinced I have become that a matter so grafted into the daily habit and thought of the whole people can only be changed by as it were the slowest absorption, and that not less than thirty-five years will be required to effect even a sem-

blance of a change after the date of the law fixing a time when the new system shall be compulsory."

At first thought this change may be thought a slight one, and Mr. Patterson's ideas exaggerated, but let any one of you who has never resided abroad think how long it would be before you could read with any degree of satisfaction such a news paragraph as the following, which will be quite common a few years after the metric system has been made compulsory:

"A blast furnace recently built about 2 myriameters from Pittsburgh, of 20 meters high and 4 meters diameter of the bosh, has recently made the unprecedented quantity of 640 metric tons of pig iron in a week. The consumption of coke was about 2 cubic meters per ton. The charge of ore was 600 kilogrammes and of limestone 120 kilogrammes per ton of product. The two blowing engines are each of 12 decimeters stroke and 22 decimeters diameter, blowing about 6.5 hectosteres of blast per minute at a pressure of 34 kilogrammes per square decimeter. The hot blast ovens have a heating surface of 20 ares, which is at the rate of 3 centiares for each stere of blast. The blast is heated to 700 degrees Centigrade, and is blown through five tuyeres, each with 2 decimeter nozzles. The ground occupied by the furnace plant contains more than 10 hectares, and will be occupied shortly by two additional furnaces, each of 25 meters high and 6 meters diameter of bosh."

We may learn a lesson of the difficulty of introducing a new system of weights and measures into any country from the experience which England is having in introducing the so-called cental system of measuring grain and other commodities. I quote the following from an English trade journal of recent date:

"The new system of weights and measures, which has now been in operation more than a year, and the infraction of which has been penal since the 1st of July last, seems to find little favor with the public. The Perth case, in which appeal was made by a railway company who were fined for using a "machine" with unstamped weights, is still undecided; meanwhile unstamped machines, steelyards, and similar illegal instruments are in use all over the country, and doubtless nine-tenths of its business is conducted by means of these "illegal" arrangements. As we noticed in a former number, the jewelers do not generally avail themselves of the decimal system provided by the Act, but continue to use the old familiar

'pennyweight,' although by so doing they make themselves *liable* to pay a penalty of £5 for each offense. Some time ago Mr. Rickard, the mathematical master at King Edward's School, put himself in communication with one or two leading jewelers of the town, offering to teach gratuitously a few classes of those engaged in the jewelry trade the new decimal system, both as applied to gold and silver and also to the precious stones. Sufficient interest could not be got up in the trade for any of them to devote one, or, at the most, two evenings to this end. Most of them still continue to work to the old system."

Another paragraph in the same paper says: "The operation of the new Weights and Measures Act is causing serious hindrance to the making of contracts in the oil trade. Under the 15th section of that Act, the standard measure of capacity is declared to be the gallon, another section providing that all trade contracts shall be made conformably to such standard. 'Secondary standards' were authorized by the Board of Trade and published in a schedule to the Act in question, but from that list what is known in the oil trade as the five-gallon measure is altogether omitted. The five-gallon measure has been recognized in the oil trade, both in this country and America—and, indeed, almost everywhere, as the usual measure of capacity. This commodity has been exported from English ports from time immemorial in five-gallon tins, and the measure so long recognized is, of course, universally known. It does, therefore, seem a peculiar hardship that two well known wholesale firms should have been lately subjected to prosecution under the Act of Parliament, for using in their trade the measure which, by common consent and usage of the trade, has always been adopted. As the inspectors insist on interpreting the new law, the effect is to put the wholesale dealer to the expense of double measures, and the consumer to the loss of having his commodity measured out twice. Oil for export will still be carried in the recognized measure of the five-gallon tin; but as the Board of Trade do not sanction the five-gallon measure, shippers must resort to the half-bushel and the gallon. We need hardly say that so serious are the consequences to an important branch of business, that some relief at the hands of the Executive is absolutely needed. As the *Daily News* points out: 'The magnitude of the interest involved may be realized from the fact that five wholesale London firms export annually in five-gallon tins alone over a million of gallons, and

this is independent both of the trade of Liverpool and other large manufacturing depots, and of the home trade of these several places."

Let it be observed that all this inconvenience is caused not by any radical change such as would ensue from the adoption of the metric system, but only by a restriction to the use in certain legal measures and weights, which are exact multiples of the old standards. Moreover the cental system applies to weights and measures of bulk or capacity only, not to lineal or surface measures. It interferes only with the measures used in buying and selling ordinary commodities. It destroys the five-gallon tin and the pennyweight, but it does not touch the two-foot rule nor the surveyor's chain. It does not destroy the value of a map, chart, drawing or book of reference. Yet, although it has been in use for over a year, it does not find favor with the public, it causes serious hindrance to business and useless expense to consumers, nine-tenths of the business is still done with the old measures in spite of the law, and annoying prosecutions are abundant.

There is no comparison between the inconvenience which is caused by the adoption of a new weight or a new measure of bulk, and that which would be caused by the adoption of a new measure of length. Who can calculate the expense and inconvenience which would ensue to every engineer and every mechanic if the division of the English foot into hundredths and thousandths were made compulsory, and its division into inches illegal? Suppose even that the change of the method of division were not made by law but by common consent of one half of the people, while the other half adhered to the division into inches and fractions of an inch, what confusion would take place until one or the other system wiped out its antagonist! But change the method of measuring length from the foot and inch system to the meter, decimeter, centimeter, and millimeter system, and the expense and confusion would be simply incalculable. Every Whitworth or other standard gauge, every yardstick, every two-foot rule (there are probably *millions* of them in use to-day), every draughtsman's scale, every drawing with figured dimensions, every engineer's pocketbook, every book of reference upon mechanical or engineering subjects in the English language, every surveyor's chain, every grooved train of rolls that rolls bars whose widths are even inches or fractions of an inch, every tap and die with a given number of threads to the inch, would be rendered, if not entirely useless, at least nearly so, for

each would require either duplication or alteration to adapt it to the metric standard. Add to the actual expense consequent upon this duplication and alteration the value of the time that would be spent by one whole generation at least in making annoying arithmetical comparisons of the two systems, and the sum total is so great as to almost justify the assertion that the change of the method of measuring lengths from the foot and inch system to the metric system is utterly impracticable and visionary. Impossible it is not. The law is no doubt strong enough to enforce the adoption of any system enacted by the legislators, but if any body of law makers, such as our Congress, should inflict such a burden upon the people without their consent, it would be the greatest invasion of the liberties of the people which has ever been attempted by a representative government.

These objections to any change in the method of measuring the lengths which are ordinarily measured in feet or inches apply, but perhaps in a less degree, to the measures of surface, including the lineal land measures, such as the rod, chain and mile. I will not further discuss this portion of the subject. They apply, however, in the least degree to measures of weight and capacity, in which England is now attempting certain reforms, as noted above. The chief objections to the substitution of the metric gramme and its multiples for the English ton, pound, etc., are the expense of changing the scales and weights now used, and the difficulty of familiarizing the people with the new units. There is no such permanent record kept of these measures as there is of measures of length. They are used in measuring commodities, then entered into books of account, and are forgotten. They are not stereotyped into every piece of machinery, map, chart, drawing, gauge and tin plate, as the foot and inch are, and the confusion resulting from the want of familiarity with them would be at an end in a very few years. The expense consequent upon the change would be a serious item, as is seen in the estimate of $125,000 for changing the scales of the Post Office Department alone, before referred to, but perhaps in time the advantages of the new system would counterbalance it.

There are two societies (if not more) in the United States, whose especial object is the introduction of the metric system in this country, viz: the American Metrological Society, in New York, and the American Metric Bureau, in Boston. They are both doing their best to establish a propaganda of the system. One issues a

Monthly Bulletin containing much valuable information. The other, when last heard from, was circulating a petition in favor of the speedy adoption of the new system to be presented to Congress. At the risk of offending my friends in these societies I must here criticise their methods in part, and offer them a word or two of unasked-for advice.

First. The metric system, if it is ever adopted in this country, must be made more simple than it is, for the easy comprehension of the common people. The American Metric Bureau publishes a list of the metric denominations, containing not less than forty terms. The whole number of terms used in the English system is only about eighty, and many of these are scarcely ever used. I present herewith a revised table of the metric system, which I think will commend itself as being much better in every way than the tables generally published. It contains only fourteen denominations:

MEASURES OF LENGTH.

Millimeter (mm)=0.039371 inch.
Meter (m)=1000 mm=39.370794 inches.
Kilometer (m)=1000 m=0.62138 mile.

MEASURES OF WEIGHT.

Milligram (mg)=0.015432 grains.
Gram (g)=1000 mg=15.43234874 grain.
Kilogram (kg)=1000 g=2.24062 lb. avoir.
Ton (t)=1000 kg=2204.62 lbs. avoir.

MEASURES OF SURFACE.

Sq. decimeter (sq. dm)=15.50059 sq. inches.
Sq. meter (sq. m) 100 sq. dm.=10.7643 sq. ft.
Hektar (hk)=10,000 sq. m=2.47114 acres.
Sq. kilometer (sq. km)=100 hk=247.113 acres.

MEASURES OF CAPACITY.

Cubic centimeter (cu. cm)=0.06103 cu. inch.
Cubic decimeter or liter (cu. dm or l)=1000 cu. cm=61.02705 cu. inches=1.0567 quarts.
Cubic meter (cu. m)=1000 liters=35.31658 cu. ft.

This table would do away with the objectionable prefixes, centi, deci, deka, hekto, myria, and would use only the prefixes mili and kilo for all measures of length and weight. The very perfection of a system of measuring is probably that of expressing a length or a weight in one denomination only. This the table enables us to do. The engineer or machinist could use the millimeter only for all short lengths, say less than a meter. For all lengths varying from a meter to a kilometer, the meter and decimals of a meter only would be used, and the dimension would be read so many meters and so many tenths, hundredths or thousandths, according as one or two or three places of decimals were used. Surveyors would use the kilometer and tenths hundredths and thousandths of a kilometer. Likewise with the measures of weight—the chemist and the physician would use the milligramme for all weights less than one gramme. For weights over one gram, the gram and decimals of a gram would be used. The grocer would use the kilogram and decimals of a kilogram only. The coal and iron merchant would use the ton and decimals of a ton. The astronomer, if he wished to express the weight of a planet, would use the ton also, even to millions of millions, so that there is no conceivable weight which might not be easily and satisfactorily expressed by one out of only four denominations. The American money table has the denominations eagles, dollars, dimes, cents and mills, but practically the dollar and the cent denominations are all that are necessary. The largest possible sum of money can be expressed in dollars and decimals of a dollar, and the smallest possible amount in fractions of a cent. The term mill is used in tax ratings, but everybody would be satisfied if this term was abolished, and tenths or hundredths of a cent substituted, as is done in the price lists of the iron trade. So the useless denominations of the metric system should be abolished, and if the advocates of the metric system would hasten the adoption of their pet they should remove this great objection to it.

The second piece of advice I would give to the advocates of the metric system is,—do not try to make us swallow the whole system at one dose, but give it in small quantities at a time. Attack us in our most vulnerable point—say the gross and net and half a dozen other kinds of tons, and leave our foot and inch, our stronghold, alone. "Divide and conquer," as the free traders are trying to do with the protectionists. Suppose, instead of trying either to get a

law passed to make the whole metric system compulsory at once after a certain date, or even trying to get public opinion to favor such a law at any future time, you do try to get a law passed introducing one little bit of the metric system first, and then follow it up with others if the first attack is successful. If you would only attack the various kinds of *tons*, you might do a great deal of good with a minimum amount of injury to anybody. Say that the legal ton hereafter shall not be 2000 lbs., 2240, 2268, 2284, 2352, or any other number of pounds now used in any trade, but 2204 62-100 pounds, and punish heavily any one who should use any other ton (especially the retail coal dealer who should use 1600 or 1800 pounds), and make the legal subdivision of the ton a decimal one into one thousandth parts, and you would have an important part of the metric system introduced with the least friction. Or you might try the quart as your first point of attack, and slightly change its volume (5 per cent. and a little over), and you could have the French liter. You might then abolish the bushel, and for large measures of bulk substitute the 1000 liter measure or cubic meter, containing about four-fifths of a chaldron. But not until all of these changes have been successfully accomplished need you ever hope to abolish this little instrument, which is in the hands of a million American mechanics to-day—the two-foot rule. Yes, first establish an international money system, successfully accomplish the reform in the spelling of the English language, teach all the nations of the earth to speak one universal language, or do any other desirable but Herculean labor which finds its chief hindrance in the habits, traditions and prejudices of millions of the human race, and you may be prepared to undertake such a revolution as would be the substitution of the meter for the two-foot rule.

That such a change in the system of measuring lengths has been accomplished in other countries is not a conclusive argument that it may be accomplished in England and America. In France, at the time of the adoption of the metric system, change was the order of the day. The people changed everything that could be changed, whether material, mental, moral or spiritual. How easy then to change their measures! In Germany the adoption of the metric system was only a welcome relief from the total confusion previously existing, when every little State had its own measures. In other countries which have adopted it, the manufacturers and mechanics, the people who use measures of lengths, formed such a

small portion of the population that their opposition to the new system, if they even were educated enough to make that opposition an intelligent one, was too feeble to cause any trouble. But in England and America the case is a different one. Here are the two great manufacturing nations of the world, including with the colonies of England nearly a hundred millions of people speaking the English language, possessing a standard of length as absolute and invariable as the French meter. Each of these two nations probably does more measuring than all the rest of the world put together. There are probably more two-foot rules in use in the world than all the meters and all the other measures of length of every kind whatever combined. And the users of these two-foot rules are the most conservative and stubborn people on the face of the earth, and they will resist the substitution of the meter to the last extremity. Therefore I say to the advocates of the metric system, leave the two-foot rule alone. Confine your Bulletins and your petitions for the next half century to the advocacy of the adoption of the French systems of weights and measures of capacity only. If you will change the measure of length, change the yardstick first, and make every man who stands behind a counter selling tape and ribbons sell them by the meter and its decimal divisions, but leave the engineer alone. The foot and the inch are the measures he believes in. For long measures he will use the mile and its subdivisions, either into tenths or into feet. For very short measurements, such as one of our members uses in measuring the elongation of a test piece, he will use a micrometer screw with divisions reading to the ten-thousandth part of an inch.

If my hearers now think that I have only "straddled" this question, and not planted myself as firmly as they could wish on one side or the other, I will now define my position. I think that theoretically the metric system is a very good system. Practically it is practicable in some things, impracticable in others. In regard to government interference I hold about the position of Ensign Stebbins on the Maine liquor law: He was in favor of the law but opposed to its enforcement.

THE TAY BRIDGE.

By A. Gottlieb, C. E.

[Read March 20, 1880.]

A terrible disaster like that connected with the failure of the Tay bridge, causes humanity to tremble, and appeals for sympathy with the unfortunate victims through the whole civilized world.

The most stupid awakens to a feeling of awe, and the news of such events spreads with unprecedented rapidity to the remotest corners of the globe.

It is unnecessary, after a lapse of weeks, to depict the horrors of the scene to any body of intelligent men, as all are familiar with the details of the calamity, and human nature prefers to draw the veil of forgetfulness over the picture of unlimited suffering.

One question suggests itself, however, to the most unconcerned: What was the cause of the calamity? For, instinctively, each one feels that such it was. The timid, as the reckless, both feel their own safety impaired; the faith in human work is shaken. While the one looks for supernatural reasons to quiet his own fears, the other condemns all the products of modern ingenuity and progress as unreliable and faulty.

The engineer feels it his duty, however, to consider calmly all the circumstances, collect all the evidence obtainable, and draw his conclusions impartially, for his own improvement as well as for the benefit of his fellow men.

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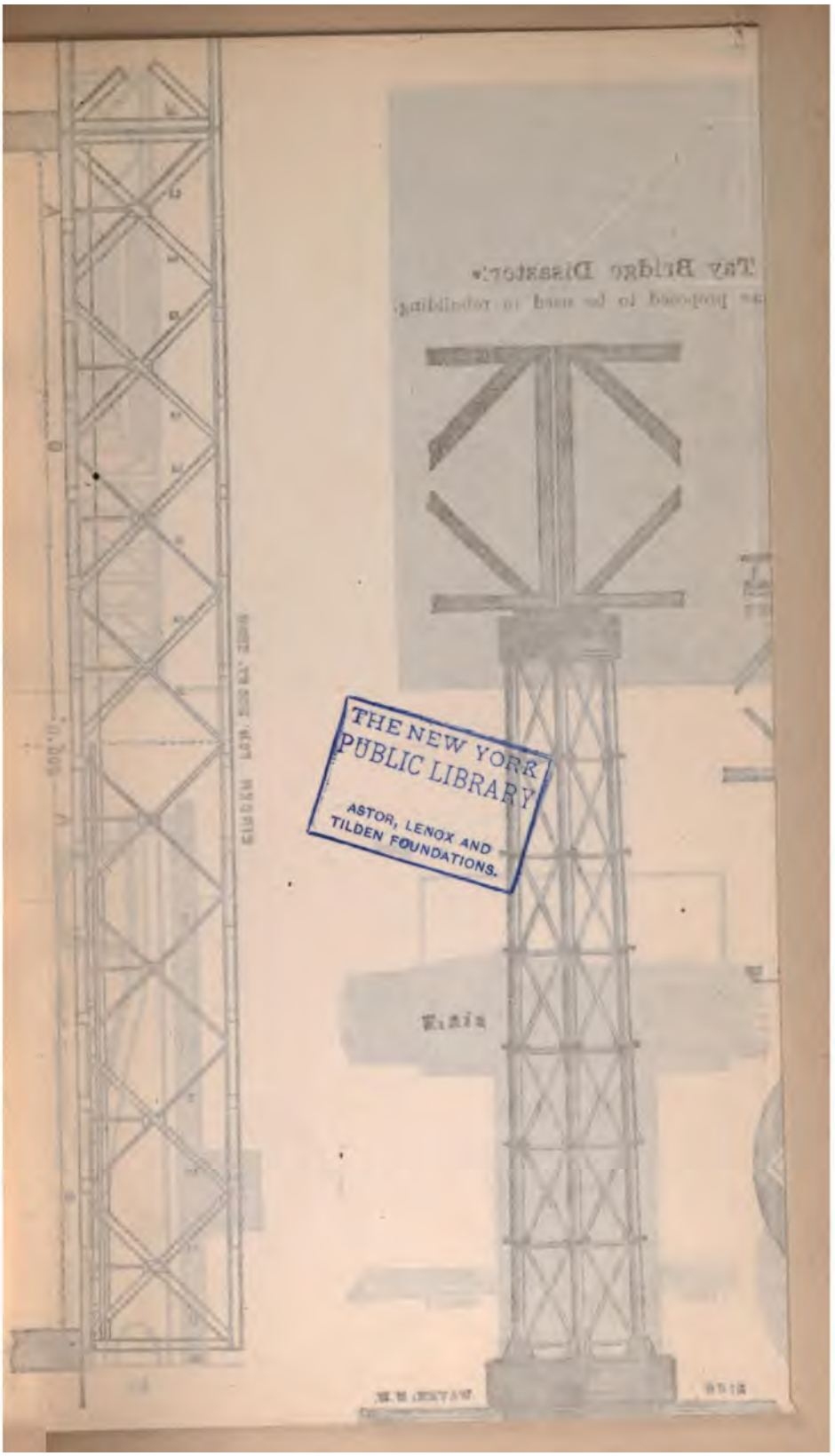
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Intending to search for the possible or probable causes of the disaster, it will be necessary to have a knowledge of the structure as it was before the failure; consider the circumstances under which it happened; and study the condition of the wreck.

The construction of the bridge connecting the south and north banks of the Firth of Tay, south of Dundee, Scotland, and carrying the tracks of the North British railway, was commenced in July, 1871, according to plans and under the supervision of Sir Thomas Bouch. As executed the bridge consisted of 85 spans, varying in length from 57 feet to 245 feet, having together an aggregate length of 10,321 feet, or nearly two miles.

Most of the spans were deck bridges, carrying the track on the upper chords, while the thirteen spans which fell formed three groups of through bridges with high trusses, and the track on the lower chords. Besides these thirteen spans there were two more through spans of smaller size, with arched upper chords, located separately at the northern end of the structure.

The foundations for the piers of the fallen spans were made of brick work and concrete, sunk in iron caissons of 31 ft. diameter and 20 ft. high, resting at a depth of about 18 ft. below the bed of the river on blue clay and gravel.

On top of this foundation brick piers of hexagonal shape, 27x16 ft. were built, capped with four courses of stone, aggregating 5 ft. in thickness; the top surface of the stone was about 5 ft. above high water. To these cap stones, as we shall see further on, the iron piers were anchored.

The construction and height of the iron piers varied to conform to the length and location of the different spans; they were of course lower for the deck spans and higher for the through spans.

The highest piers supporting the thirteen fallen spans were about 82 ft. from top of cap stone to the top of the transverse girders supporting the trusses. There was a grade on both approaches to these spans, but on them the track was level.

The iron piers were formed by six cast iron columns, filled with concrete; each column made in seven sections provided with male and female ends, and connected through flanges with eight bolts of $1\frac{1}{8}$ in. diameter to each joint.

At their bases the columns were bolted to iron base plates, which in turn were resting on, and were anchored to, the cap stones of masonry with four bolts of $1\frac{3}{4}$ in. diameter.

Of the six columns forming a pier, four were of 15 in. diameter with 1⅛ in. thickness of metal, and placed in pairs 12 ft. apart at the bottom and 10 ft. on top, in the direction of the bridge, while transversely they were 10 ft. apart throughout. The other two columns were 18 in. in diameter with 1¼ in. thickness of metal, and placed singly one on each side, bearing near the point of the hexagonal pier, with a base of 21 ft. 6 in. transversely to the bridge, and 19 ft. 6 in. apart at the top; or in other words, having a batter of one foot, to the full height of 82 ft. These two 18 in. columns are called the cutwater columns.

From what our further observations will prove, it seems almost justifiable to assume that these two columns were constructed and located with the sole object to perform that office only which above term implies.

At each joint, or tier, the cluster of columns was braced by horizontal perimeter struts of two channel bars 6½x2½x½ in., back to back, 2½ in. apart, or together of about 10.5 square in. section, and by diagonal ties 4½x½ in. There were also horizontal diagonal rods, and horizontal struts parallel to bridge, in each tier between the 15 in. columns.

The connection of the perimeter struts and diagonal tiers with the columns was effected by means of cast iron lugs and bolts; but the connection was not made on the same lug for both, but to separate ones, some distance apart.

I have observed this practice in English structures generally, to attach the compression and tension members of bracings at different points with the main structure—which is not an admirable one. While it is theoretically wrong, it is not as dangerous in wrought iron riveted connections as with cast iron lugs; in the latter case the method is absolutely condemnable. It is easier and cheaper to employ such details than others, but in structures involving public safety, particularly in such exposed localities as that of the Tay bridge, they never should be used.

On top of the iron columns were riveted cross girders of the shape of an A, which supported the trusses of the bridge.

Of the thirteen spans, eleven were of 245 ft. length and two of 227 ft. each.

It seems that it was originally intended to have all thirteen spans of the length of 245 ft., but that the shortening of two was due to an after consideration, on account of the foundations.

The trusses were of a double triangular system, divided into nine panels of 27 ft. each, and 27 ft. high, with vertical suspenders from the intersection points of the diagonal web members. The trusses were placed 15 ft. 6 in. apart from centre to centre, which brought their support about midway between the single 18 in. column and the next adjoining pair of 15 in. columns. The chords were of a trough or channel shape, the largest 16 in. deep by 24 in. wide, the smallest 10 in. deep by 15 in. wide.

The diagonal struts were of I beam shape, 15 in. across by 12 ft. 9 in., and 6 in. wide in the length of bridge; the diagonal ties were $\frac{1}{2}$ in. thick, varying in width from 20 in. to 12 in. On the lower chords, 5 ft. apart, were the iron crossbeams, supporting 14x14 wooden stringers under the rails, and the whole floor covered with 3 in. planks. There was also a system of lateral bracing between the upper and lower chords, the dimensions and details of which I do not know. Where the through spans adjoined the deck spans, they were supported by a wrought iron riveted box, which acted at the same time as end post for the deck span.

Calling the iron pier at the northern end of the most southerly span pier No. 1, the spans were so coupled that at piers No. 5 and No. 9 they were disconnected, and provisions made for expansion and contraction, while over the other piers they were continuous.

The history of the fall of the bridge is familiar to every one, so I need dwell but briefly on this point.

At about 7 P. M. of December 27th, a train from Edinburgh, consisting of engine and tender and seven cars, proceeded from the south end of the bridge towards the north to Dundee, while a severe gale was blowing.

The train was watched by parties on both sides, and was seen to proceed steadily until it reached about the point where the thirteen through spans were, when it suddenly disappeared, amidst a burst of fire and light.

No noise was heard above the roaring voice of the gale, when the train and all on board were precipitated into the watery grave.

From observations by Prof. Robert Grant, of the University of Glasgow, we learn that at the time the train disappeared from the bridge the wind was blowing from W. S. W., and attained a velocity up to 90 miles per hour in sudden bursts, which is about equivalent to a pressure of 40 lbs. per square foot of an exposed surface at right angle to the direction of the wind.

It will be well to remember here, that the bridge at the site of the thirteen spans run about direct from S. to N., and that the wind during the afternoon was mostly from S. W., veering round sometimes to S. E., and at the time of the fall was W. S. W. This fact will justify us to assume, in the further investigation, that more than the surface of one truss was exposed to the action of the wind.

From reports so far known, we learn that the engine and tender and three carriages were found between the fourth and fifth piers, the engine about 50 feet south of the latter. The wreck is on the east side from the piers. The condition of the piers is briefly as follows :

On the pier supporting the north end of deck spans and the south end of the through spans the columns are cracked and bolts sheared off, one bolt $1\frac{1}{4}$ in. diameter at southwest corner broken by tension $\frac{1}{2}$ in. from top of column flange.

On pier No. 1.—Two lengths of columns are standing with their tie rods and foundation plates.

Pier No. 2.—The six foundation plates intact, with some portions of columns remaining.

Pier No. 3.—About the same as No. 2.

Pier No. 4.—Foundation plates intact, portions of the six columns attached *hanging over to west.*

In the above four piers no stone work is disturbed.

Pier No. 5.—The west stone of cap is lifted up; the anchor bolts passing through two courses only. Base plate is attached to stone; all the columns are gone.

Pier No. 6.—Foundation plates intact; column broken through flanges or bolts.

Piers Nos. 7 and 8.—About same as No. 6.

Pier No. 9.—Same as No. 5, but worse. Here the dowel bolts connecting the courses of cap stones pass through the upper two layers only, and not quite through the third; the anchor bolts of base plates pass through one course only.

Pier No. 10.—Stone work is little disturbed; columns gone.

Pier No. 11.—Stone work suffered considerably; three foundation plates gone.

Pier No. 12.—On the west corner a cap stone of the upper course about 4 ft. square gone, and the stone below about 6 ft. by 6 ft. 6 in., is broken through the bolt holes. Anchor bolts went through two

courses only. Five base plates are in place, the sixth is gone with the stone. Four lengths of columns are lying on pier. Judging from their position, the canting over of the structure has first been towards east, but falling it was set back towards west.

No. 13, or pier under deck span, north of through spans, is in a worse condition than the corresponding pier on the south end.

WHAT WAS THE CAUSE OF THE FAILURE?

This all-important question suggested itself undoubtedly to every engineer, when he read the news of the disaster, particularly the engineer engaged in the construction of bridges. Although at first the data were scarce, my own first impression was, that a derailment of the train and the consequent destruction of one or more spans, which then had caused the fall of the balance of the structure, was out of question.

The train, as described, was shorter than one of the spans, and it is not to be supposed that if one span had been destroyed, and even at the centre of the group, it would have carried with it all the rest, that is at least six spans on one side.

Considering the reports of the then existing gale, combined with the fact that just the thirteen spans had failed which had the highest trusses and were on the highest piers, that no noise was heard on the shores when the train disappeared, all this led me to believe the failure was due to the effect of the wind, and that, moreover, the spans had disappeared before the train had reached the southern end of the present gap. Subsequent developments have, however, demonstrated this to be erroneous, as the wreck of the train is reported as lying between the fourth and fifth piers, and caged in between the trusses.

But the subsequent calculations will prove that, although the train was on the bridge when it failed, the structure was doomed to destruction even without it.

Assuming the dead load of the superstructure at 200 tons, we find that by the peculiar location of the trusses over the iron piers one-quarter of the load, or 50 tons, was supported by each pair of 15 in. columns and single 18 in. column.

The surface of one truss, exclusive of the heads of floorbeams, sides of track stringers and rails, I compute to have been 1200

square ft.; to this added the surface of above mentioned floor members with 300 square ft., would give 1500 square ft. of surface, if assumed that the direction of the wind was at right angle to the side of the bridge, and that one truss covered and protected completely the other.

But for reasons previously stated, this assumption is inadmissible. The most favorable allowance in favor of the stability of the structure will be if we assume that one-half of the surface of the leeward truss was also exposed to the action of the wind, which would give the total surface 1500+600=2100 square ft.

Taking the pressure of the wind with 40 lbs. per square ft. gives a total pressure of 84,000 lbs.=38 tons. This force acting at the centre of the truss, trying to overturn the structure around a fulcrum at the base of end posts of the leeward truss, its moment will be $38 \times 13\frac{1}{2}=513$ foot tons. Opposed to this moment will act the weight of the windward truss, plus one-half of the weight of the floor, or say one-half of the weight of one span=100 tons, with a lever equal to the distance between centres of truss=$15\frac{1}{2}$ ft., which gives a moment of 1550 ft. tons.

We see, therefore, that the stability of the trusses was largely in excess of the wind power; provided the systems of lateral bracings between the upper and lower chords were perfect.

The position and condition of the wreck point, however, to the conclusion that the trusses were turned over together with the iron piers, and the following will show the possibility of the case :

Disregarding the train entirely, the following pressures produced by the wind acted upon the trusses and piers for one 245 ft. span:

On the side of the trusses a force of 38 tons in the middle of their height; consequently with a lever arm of $13\frac{1}{2}+82=95.5$ ft., considering as fulcrum the base of the leeward cutwater column.

Considering all the columns and braces of the piers as exposed to the wind, the surface of each of the seven tiers is 130 square ft., and multiplied with 40 lbs. gives a pressure of 5200 lbs.=2.3 tons. The lever arms for these forces to overturn the structure around the same fulcrum as above, will be 70.4, 59.56, 48.73, 37.09, 27.07, 16.24, and 5.71 ft. for the respective tiers.

The total moment for overturning the structure will consequently be:

$38 \times 95.5+2.3\,[70.3+59.56+48.73+37.90+27.07+16.24+5.41]=$ 4239 ft. tons.

Taking the weight of trusses=200 tons, and of the pier, 90 tons, the rightening moment will be $200\times10.75+90\times10.75=3117$ ft. tons.

We see, therefore, that the moment trying to overturn the structure is by 1122 ft. tons larger than the rightening one.

From the same data we can find that a wind pressure of 30 lbs. per one square foot would have been sufficient to just balance the stability of the structure.

From the English engineering papers we obtain the data that the exposed surface of the train was about 1600 square ft., while its weight was 120 tons. The wind pressure on the side of the train would therefore have been $1600\times40=64000$ lbs.=29 tons, and considering this pressure acting at the middle of the height of the cars, its overturning moment will be $89\times29=2581$ ft. tons. The rightening moment for the weight of the train will be similarly as that from the weight of trusses=$120\times10.75=1290$ ft. tons.

Combining these moments with the previous moments of the empty spans, we find the total moment for overturning will be:

$4239+2581=6820$ ft. tons, while the total rightening moment will be=$3117+1290=4407$ ft. tons. The excess of the overturning moment is therefore=2413 ft. tons, which is more than twice as much as if the span was empty. A wind pressure of 26 lbs. per one square ft. of surface, on the train and structure, would have been sufficient to balance the moment of stability of the loaded span.

Let us now consider the effect of the overturning moment upon the structure, when there was no train upon it.

The excess of the overturning moment, over the moment for stability, was then 1122 ft. tons. This was under the supposition that the structure had to resist overturning by its own dead weight, without considering any resistance from anchorage.

We know, however, from the previous description, that the bases of the columns were anchored through two courses of cap stones, and know, also, from the description of the wreck, that the largest stones which broke loose from the pier with any one column amounted to about 54 cubic ft., or about 4 tons. The 4 tons acting at a lever arm of 21.5 ft. would increase the moment of stability by $4\times21.5=86$ ft. tons.

Assuming that the anchorage at base of 15 in. columns also represented a weight of 4 tons each, their lever arms being 15.75 and

5.75 respectively, the total moment in favor of stability from the anchorage would be: $4\times21.5+8\times15.75+8\times5.75=258$ ft. tons, which, deducted from 1122, leaves 864 ft. tons as excess of the overturning moment.

A wind pressure of $32\frac{1}{2}$ lbs. per square ft. on the empty spans and of $28\frac{1}{2}$ lbs. per square ft. on the loaded spans would have balanced the moment of stability, if the anchorage of the columns is considered.

Now suppose the leeward cutwater column strong enough to resist the total load thrown upon it by the uplifted structure while being overturned, we find that the anchor bolts, fastening the bed plates to stone caps, being four bolts $1\frac{3}{4}$ in. diameter, would have each to resist $\frac{1122}{4\times21.5}=13.0$ tons, or 7.4 tons per 1 square in. of section, assuming the diameter of bolts between threads as $1\frac{1}{2}$ inches.

The eight bolts $1\frac{1}{8}$ in. diameter, coupling the lowest tier of columns to base castings, being about 15-16 in. diameter between threads, would be strained to $\frac{1122}{8\times21.5}=6.5$ tons or 9.4 tons per one square in. of section.

The sectional area of one 18 in. column being 66 square inches the strain per square in.

$$\text{therefore}=\frac{1122}{21.5\times66}=0.8 \text{ ton.}$$

These unit strains on bolts and columns would be doubled on the span where the train was, and would for the coupling bolts reach the ultimate strength of wrought iron, while in the anchor bolts the elastic limit would have been far overrun, and the point of rupture approached.

Computing the strains in the diagonals from the data given, we shall find that the $4\frac{1}{2}\text{x}\frac{1}{2}$ diagonals at the lowest tier between the windward cutwater column and the adjoining 15 in. columns, when the spans were empty and overturning, had to resist a strain of $\frac{50+17\times1.25=41.87}{2}$ tons, or 18.5 tons per square inch.

For the two diagonals between the 15 in. columns and the leeward 18 in. column the strain would be=$\frac{1}{2}$ (3×50+17+4×14) 1.25 =139.4 tons, or 62 tons per one square in., which is more than twice as much as the ultimate strength of the best wrought iron.

It is not necessary to investigate any further how these diagonals will have been strained in the span loaded with the train.

It remains only to be seen how the leeward cutwater column would have resisted the strains imposed on it, on the supposition that the overturning should have occurred around its base, and that all the bracing between the various sections was perfect.

The load carried by the lowest section of that column would have been the total load of span plus pier=290 tons, without considering the train. The ultimate strength, taking the length of column at 10 ft. 10 in., according to Rankin's formulæ would be 69,500 lbs.=31 tons per square inch, or for the whole area, 66×31=2046 tons.

The leeward column would therefore have supported the weight of the empty span, while being overturned with a factor of safety of seven; provided the bracing between columns had been strong enough. But the diagonal bracing was of such a character that the ties would have broken in the uppermost tier the very moment the windward columns had been lifted from their bearings, which would have left the entire length of the leeward (18 in.) column without bracing, and considering then the whole as one column of 76 ft. height its ultimate strength would have been 9500 lbs.×66 =280 tons, which is nearly the load actually imposed upon that column in the empty spans, and less than the weight on that column in the loaded span.

It is not necessary to consider the case, that the overturning should have taken place around a fulcrum at the base of the two leeward 15 in. columns, as such a case could not have happened before the cutwater column gave way, and in this case the whole superstructure would have fallen without any further cause, as the cutwater column had to carry part of the weight of the superstructure direct.

In all these calculations we have disregarded the possibility that the wind force struck the planked floor of the roadway, which offered such a large surface to the destroying power; but it can be assumed with almost certainty that such was the case.

Enough has been shown, however, to form a clear idea of the causes of the failure.

Granting that all the material used in the construction was first-class, which is very doubtful judging from latest reports, the principal causes of the destruction of the Tay bridge must be attributed:

1. To the insufficient base between the cutwater columns.
2. To the use of cast iron in the piers.
3. To the bad anchorage of columns to the masonry.
4. To the deficiency in strength in the diagonal bracing and the poor details of their connection with the columns of the piers.
5. To the location of the trusses about midway between the cutwater columns and the 15 in. columns.

If these points will be duly considered in the reconstruction of the bridge, which by necessity will have to be undertaken sooner or later, I have no doubt the structure can be rebuilt to weather the severest gales successfully. The results of the calculations show that a wind pressure of 22½ lbs. per square ft. on the exposed surface of the windward truss, plus one-half the surface of the leeward truss and their piers, was sufficient to just balance the stability of the structure, when there was no train on the bridge.

Considering now the fact that this assumption was a very favorable one, and that trustworthy observations prove the wind pressure at times to have been 40 lbs. per square ft., and probably more under sudden bursts of the wind, there is no reason I can perceive why the destruction of at least part of the bridge should not have been accomplished before the train reached the southern end of the present gap.

From the description of the wreck it seems certain to me the wind spent its force in the first place at the northern end of the structure, which was the remotest from the train. As the gale blew from W. S. W., it is probable that the seven deck spans of 146 ft., resting on lower piers and preceding the thirteen through spans, broke the force of the wind and diverted its direction so as to protect the higher piers of the through spans at the southern end; this explains to me why the iron stumps on piers No. 1 and 2 are there, and the piers generally of the southern group of spans are in better condition than the rest.

This reason, also, leads me to believe that the group of the south five spans was the last to fall, as it required the additional surface of the train to make up in some measure for the lost power of

the wind at the extreme south end, and that the train could proceed as far north as the fifth pier before these five spans failed.

The fact that on pier No. 4 some columns are hanging over to the west, while on all other piers the wreck is swept clear off to the east, shows that there was a struggle before the spans and piers gave way, that the structure waved forth and back before the wind acquired strength enough to accomplish its destructive mission.

Although the spans were in groups continuous over piers for vertical loads, they cannot be considered as such for pressures on the side of trusses.

The upper chords and upper halves of trusses generally, under the wind pressure, were under the same strains as a beam of the total length of their chords would be under a uniform load; and the lower halves of trusses were partially so, as the only resistance offered was the friction produced over the piers by the dead load of the structure, which was not of such magnitude as to be equivalent to a firm support.

In this way the wind force acting at the piers, under the extreme ends of the groups, would be almost corresponding to the shearing force at the ends of a beam under an uniformly distributed load, which in our case would produce the largest attacking force at the top of the piers 5 and 9, where the trusses were disconnected, and probably one end firmly anchored, while the other was on expansion rollers. This may explain why these piers, Nos. 5 and 9, are in the worst condition, having uplifted part of the cap stones with the anchor bolts, and disturbed the masonry in other places.

It will be better, therefore, to rebuild the bridge with independent spans; and it will also be well to give a separate, independent set of columns to each span, placing the bearing columns directly under the ends of trusses and let the cutwater columns act as braces only, without taking any part in carrying the load, under normal conditions.

Piers No. 11 and 12 being comparatively in the middle of the group of continuous girders at the northern end, show as bad effects on the masonry as the piers No. 5 and 9; and as there was no train on those spans it is reasonable to assume that the force of the wind must have been the strongest there, and that consequently these spans failed first.

The central group of four spans, containing two spans of 227 ft. each and two spans of 245 ft. each, offered therefore less surface to re-

sist the wind force than the four spans of 245 ft. to the north of them, and probably for this reason failed next; while the group of the five most southerly spans failed last, for reasons previously stated.

Although it is here assumed that the groups of spans fell successively, which is also borne out by some testimony of eye witnesses, the whole time required to accomplish the fearful ruin was probably shorter than it takes to read these few sentences stating the probable cause of it.

In conclusion it may be of some interest to quote from a little pamphlet, issued at Dundee, 1878, the predictions of a seer with name Matthews, in regard to the Tay bridge :

"The town council, most of the public bodies, and the inhabitants of Dundee being now convinced of the practicability of bridging the Tay between Wornsit on the south and Buckingham Point on the north, and that the completion of such an undertaking was simply a question of time and money, it might have been expected that no other voice would be raised in opposition, and no further unfavorable criticism offered. But no. During the six years the scheme of Mr. Bouch had been under discussion the seer of Gourdie Hill had been so absorbed in his incantations to the powers of Nature that he failed to comprehend the change which public opinion had undergone regarding it, or to mark the progress which had been made towards its realization. But when the resolution to proceed caught his eye, the fairy curtain which obscured the face of his magic mirror is drawn up like the mist from the brow of a mountain, and he beheld the bridge completed.

" It is a high, slender, rainbow-like structure, having a barrier of strong palisades on either side to protect it from the fury of the waves and the destroying breath proceeding from the 'storm-throat' of the Tay.

" The piers of the bridge and its protecting palisades have the effect of increasing the velocity of the currents, and these in their turn are scooping out deep channels which threaten to destroy the foundations, while the mud and sand disturbed in the process are forming enormous banks, which will eventually obstruct the entrance to the harbor, and perhaps endanger the fairway at the mouth of the river itself. But there is still another danger. He sees a ship, which has slipped its anchor during a storm. It is drifting up the river, manned by a drunken crew, who, regardless of the consequences, allow it to run against a pier, and, strange to say, the

ship is uninjured by the shock, while the bridge is toppled over like a child's house of cards.

"Yet a little while and a train filled with happy people is swiftly proceeding along the tortuous structure. Its weight and velocity act with such a centrifugal force upon the curve that the workmanship is unable to bear the strain, and he sees the bridge open up and the train, with its human freight, precipitated into the river a hundred feet below. An islet is now seen in the firth, where no islet existed before, and its component parts are loose stones, fragments of iron and of wood, together with mangled human bodies, and the eels are gliding out and in between the interstices of the horrible scene. The bridge itself is a wreck, and never more will be used as a medium of communication between the counties of Fife and Forfar. And yet once more. A giant, restless in his sleep, is seen struggling under the district of Comrie. At every turn the monster makes the earth is shaken as if subjected to an attack of palsy, and the radius within which these shakings and tremblings are felt includes the Carse of Gourdie and—Dundee! A shake which scarcely moves the tallest and most slender chimney in the smoke begrimed town has ample power to throw the rainbow bridge into the Tay, and all the powers which men can exercise can hardly set it up again.

"Thus the seer predicted the fate of the great undertaking in a series of eight letters written to the Dundee *Advertiser*, beginning on the 7th of September, 1869, and ending on the 11th of March, 1870.

"Through whatever medium the bridge might be viewed, Mr. Matthew saw nothing but disaster, and it is a question had he lived to witness the heavy ballast trains which have daily crossed the Tay by its iron roadway, whether he would not have found some other agent as a substitute for that centrifugal force which has so treacherously failed to aid him in the fulfillment of his predictions."

The scene of horror at the time of the disaster must have baffled any description ; but this prediction of the seer depicts the scene as shockingly true as it possibly could have been. Although the result is stated with terrible accuracy, the cause of it was somewhat at variance from those enumerated by him ; but from what we found, we know that the prediction of the final cause did not necessarily come within the scope of a seer.

CONSTITUTION OF EARTHS AND SLIPS IN CLAYEY SOILS.

TRANSLATED BY LIEUT. F. A. MAHAN.

[From an article in the "Annales des Ponts et Chaussées," by M. Rene Lefebvre, and read April 20, 1880.]

The presence of clay in the slopes of a cut or fill may cause slips of a special sort, which have occupied the attention of engineers for a long time, and which occupy it still more now that the construction of railroads has made it necessary to move large quantities of earth. As a general rule, these slips can only be prevented and repaired at great expense. It even happens that the difficulties have been such that it was impossible to overcome them, and the original line laid out and the arrangements at first made, have had to be abandoned.

Vauban had to struggle against these difficulties in fortifications. He merely pointed them out without clearly investigating their causes, and without giving any definite means of opposing them.

Girard also met them in making the cut in the Saint Denis Wood for the construction of the Ourcq canal. He observed the slips with more care and attributed them to the oozing out of water at the surface of thin layers of clay. In his view these layers of clay, when they slope towards the cut, form so many pre-existing sliding surfaces along which the upper mass moves when the water has lubricated the clay and destroyed the friction.

The first important special work that we know on this subject is an article published in 1846 by M. Collin. In his article this engineer makes it his study to oppose the idea of the pre-existence of sliding surfaces. He is of opinion that the united and soapy surface observed by Girard is not the cause but the consequence of the slip. He attributes the breaking of equilibrium to a passive force: the destruction of the cohesion of the clayey masses by the action of water, and to an active force: the weight of the mass of earth. What he tries especially to show, by the result of a large number of observations, is that the breaking of equilibrium takes place along a curved surface, the section of which, made by a vertical plane in the direction of motion, is an arc of a cycloid or of a curve of this family.

In an article published in 1851, M. de Sazilly, profiting by the observations of M. Collin, and adopting his idea as to the mode of forming the sliding surfaces, attributes the movements to the softening of the loam by the action of surface and interior water, and to its crushing under the weight of the upper masses of earth.

The great merit of M. de Sazilly's work consists in pointing out a system of arrangements fit to prevent slips, and especially a new method of protecting slopes from the action of water. His method successfully applied in a great many cases, has given great authority to his ideas, but the theory by which he explains the formation of slips is not sufficient. Moreover, it has not been admitted without dispute by all engineers.

M. Chaperon, in a short article published in 1853, points out certain movements that M. de Sazilly's theory does not explain, and that could not possibly be prevented by his method. Other engineers, going further than M. Chaperon, deny altogether the efficaciousness of this preventive method. We think it unjust to go so far as these last. We are able to mention, by experience, undoubtedly excellent results given by M. de Sazilly's method in certain cases, but we have also seen its well known insufficiency in others.

We have been led to a more careful study of this subject by the important slips that have taken place in two cuts on the railroad between Epinay and Luzarches, and we have seen that these accidents were not due, as has been thought heretofore, to the giving way of the earth, but to the thrust of the water that had accumulated in the fissures that cross the clayey masses. We propose to give in this article the result of our observations.

I.—CONSTITUTION OF EARTHS.

One point now universally admitted is, that the slips which take place in clayey earths are due to the action of water and to its penetration into the mass. Hence we must study most carefully the way in which this penetration takes place.

Cohesion of Earths.—Earths are made up of particles more or less fine, more or less close together, and having, to a greater or less degree, the property of sticking to each other.

Cohesion varies very much with the nature of the earths. We know that the elements which compose them are almost exclusively silica, lime and clay. Cohesion seems to be nothing or very weak in silica; weak, but existing to a certain extent in lime; highly developed in clay.

The particles of which earths are made up have voids between them through which water can enter and circulate. This faculty for penetrating and circulating is the less as the particles are smaller and adhere more closely. It is well developed only in earths made up of large grains, and more especially when these grains are siliceous. When the grains are small, even when no cohesion exists, it is almost nothing. This is why very fine sand is, so to speak, impermeable, and is used to make perfectly tight coffer-dams.

Hence the permeability of earths is due only in very rare cases to the voids existing between the particles.

The cohesion of the particles of the same earth varies with the degree of its dampness A pure, very fine sand, without cohesion when dry, acquires it to an appreciable extent when moist. The same holds good for calcareous and clayey earths. On the other hand, beyond a certain degree the cohesion becomes less when the quantity of water mixed with the mass is increased. It may even cease to exist, and it is thus that earths take the consistency of mud and even pass to the liquid state.

The permeability through the voids between the particles varies in like manner with the cohesion. A sand permeable when dry is much less so when it reaches a certain degree of dampness.

Definition of Seams.—When the particles composing earths are endowed with cohesion, they group themselves and form fragments of which the consistency approaches that of solids. This grouping in masses is made more or less easily, and is controlled by differen

laws, according to the nature of the particles. It involves a special mode of division of the mass, which may be then crossed by fissures of which the continuity, regularity, extent and opening vary with circumstances. These fissures were pointed out in clay by M. de Sazilly, who called them cleavage planes. But this expression does not seem to be strictly correct. It only indicates a tendency towards separation, whereas in most cases the separation is complete. We have heard workmen call them *seams*, and we think this name better. Quarrymen give the general name of seam to fissures normal to the planes of stratification, formed in stratified rocks, and the divisions in earths are much like those in rocks. Hence it is proper to give them the same name.

Mode of Forming Seams.—The faculty of forming seams does not exist in earths between the particles of which cohesion does not exist. It appears, however, when cohesion begins. Dry earths in a state of dust never have seams, but it is easy to show their existence in mould and even in fine and very pure sand, however little moist it may be.

According as cohesion is more or less great, seams are formed under different conditions. They are rare, slightly marked, continuous and generally vertical when cohesion is slight, as in earths where silica is predominant. They are more numerous, more marked, but still regular, continuous and generally vertical in earths of medium consistency, as in those where lime is predominant. They are very numerous, wholly irregular, and may be very strongly marked in earths which are mostly made up of clay.

Part Taken by Seams.—Seams are the passages through which water penetrates into the masses of earth that cannot give it an easy passage through the voids between the particles. They are almost the sole cause of these masses being penetrated or traversed by water. Hence it follows that water enters deeper and more readily into earth composed of very fine particles when cohesion is strong than when it is weak. It enters deeper into calcareous, and even into vegetable earths than into silicious earths composed of very fine grains. This explains why it is easier to make coffer dams with very fine sand and mould than with clay. The water that enters the seams disappears rapidly, by absorption into the mass, in earths of little cohesion ; it is kept longer in earths of mean cohesion and may be kept indefinitely in earths of strong cohesion, as in pure clay. From this it follows that disaggregation

or the destruction of cohesion, by excess of water, is caused rather by absorption in earths of slight cohesion. In those of strong cohesion, on the contrary, it is caused almost exclusively by the successive opening of seams, reducing the mass into smaller and smaller fragments until the division becomes sufficiently fine to convert the earth into mud or to make it altogether liquid.

The passage and stay of water in the seams of argillaceous earths are shown by a bright film coating the sides of these seams, and by threads and even pockets of water found in these earths when a cut is made therein. This bright appearance of the sides of the seam differs essentially from that presented by the sliding surfaces of soft clay. We may say that both of these surfaces have a soapy appearance, but in spite of this resemblance they are easily told apart. The sliding surfaces are regular, smooth, sometimes striated, whereas the sides of seams are irregular, mammillated, and show no signs of streaks when opened in earths where no movement has taken place.

Seams are, moreover, in most cases, the cause of the permeability of earths. This permeability depends not only on the number and width of these seams, but also on their direction. Thus, in earths where lime predominates, and where seams are continuous and regular, the permeability will be greater than in argillaceous earths, because the seams in the latter, although more numerous and open under like conditions, are more irregular and less continuous. What also helps to make argillaceous soils less permeable is the property possessed by clay of enlarging under the influence of moisture. In consequence of this property seams may close up when water comes in. Seams in closing may even disappear entirely on account of the strong cohesion of clay which works together under the action of pressure, and the new seams that open during a new dry spell do not necessarily occupy the same places as the old ones. Thus penetrability depends both on the size of the particles that compose an earth, on cohesion and on its faculty for shrinking. It is greater for earths made up of coarse particles, as cohesion is less. It is greater for earths made up of fine particles, as cohesion is greater, and as the earths are subject to greater shrinkage. On the other hand permeability depends moreover on the direction that the seams may take, so that instead of increasing indefinitely with cohesion in earths made up of very tenuous particles, it will decrease beyond a certain limit in proportion to the irregularity of the seams.

Seams also allow the air to circulate through the masses of earth and hasten their drying. Through them the roots of plants develop and seek, often at great distances, the water necessary for growth. The presence of water preserved in seams of argillaceous earths often determines the formation of those white roots that may reach a great length. The existence of these roots is not prolonged apparently beyond the time necessary to accomplish their function, which is to supply water to the plant during the dryness of summer. When rains come and the seams in the clay are closed, they are crushed and die. Their remains then produce those matters having a vegetable appearance, which may be compared to fern leaves, of which M. de Sazilly mentions the existence in the cleavage planes. The observations of roots in various stages of decomposition leaves no doubt in our mind on this point.

Finally, seams lessen the consistency of the earths that they cross. When they are extensive, regular, continuous and persistent, they form true pre-existing surfaces of separation, which, under certain circumstances, may have a great influence on the stability of the earth. It is these seams, generally vertical in the mould or vegetable earth found at the surface of the ground, that allow the method of working by breaking off large masses. It also cannot be denied that they facilitate work with the pick, and that if the skill possessed by certain earth-workers is due to their strength and dexterity, it is also increased by their aptness in seeing the direction of the seams and in making use of them in their work.

Effect of the Penetration of Water into Clayey Earths.—If we studied more carefully the consequences of the penetration of water into clayey earths, we should see that, resting in the seams, it exerts on the sides of the seams a pressure that up to the present time has not been taken into account. It is not necessary to say how this pressure acts, which is none other than the hydrostatic pressure in close vessels. We shall merely say that a very small quantity of water may there develop a great force. This pressure, tending to open the seam, may cause a movement of the mass, but it may also act simply by aiding the entrance of the water to a greater depth in the earth.

When a clayey mass is cracked during the dry season, rain water enters the seams. The first effect of this water coming in contact with the clay is to make it swell up and the seams close. If the cohesion be great enough they may disappear entirely. A new dry

spell makes new ones open, which disappear in their turn, so that clayey masses are in a state of perpetual motion, in which their molecules are displaced. The seams do not close without a certain amount of water being enclosed in the mass where it may travel around under the influence of the alternate motions of shrinking and swelling. The incompressibility of this water may have some influence on the nature of the motion, which, instead of being a simple oscillation, may be accompanied by a relative displacement of the molecules. This displacement, small at first, may become very sensible as it is reproduced. After a while the relative positions of the molecules may be entirely changed. This is perhaps the cause of the up-turning presented by certain clayey masses, and of the remarkable irregularity with which sand, gravel, marl and clay are distributed through it.

These successive reactions of the different parts of clayey masses against each other, every time that wet follows dryness, form a sort of elasticity. But this elasticity only exists when the mass is held up on all sides. If the support on one side be gone, the elasticity normal to the plane where the support is wanting is destroyed. The introduction of water into seams, instead of causing a reaction, gives rise to a motion towards the vacancy, this motion being caused by the swelling of the clay and by the hydrostatic pressure in the seams. This motion may cause a general expansion of the mass, giving it greater opportunities for disintegration ; it may cause, more especially, the opening of a seam along which the separation takes place. In this case the separated mass remains solid and moves in a body.

It follows from what we have said on the constitution of earths, that the beginning of all disaggregation, and consequently of every slip in clayey earths, is the opening of seams under the action of hydrostatic pressure. If we wish then to investigate the way in which these slips are produced, we must not imagine a clay more or less softened and consider its tendency to crush under the weight of the upper masses, but we must study the way in which the seams are made and opened. The first starting point was that of MM. Collin and de Sazilly, and on this account their theory is defective. At least we think that the remainder of this article will show it.

Classification of Earths according to their Permeability and Penetrability.—When we study the causes of slips in clayey masses, we are led to consider the relative permeability and pene-

trability of the overlying earths. Up to the present time they have only been classed as permeable and impermeable. What has just been said must cause a more precise classification. In permeable earths we must distinguish:

1. Eminently permeable earths; that is, those which owe their permeability to voids existing between their particles. These earths may be traversed by water in every direction, this water forming a true layer. Of this sort are gravel and very pure, coarse sand.

2. Slightly permeable earths, which only owe their permeability to the existence of the seams that cross them, and consequently only allow the water to pass in the direction of these seams. In this class are the vegetable earths, moulds with little clay, fine pure sand, slightly clayey sands, so long as they are not incorporated in a clayey mass, slightly seamed calcareous marls, slightly clayey marls.

On the other hand, in the impermeable earths we find:

1. Clayey earths; that is, those which, on account of the presence of clay and the arrangement of their seams, cannot be traversed by water, but can be penetrated to a greater or less depth, this penetration being always followed by a swelling that stops the entrance of water and works the mass together. Besides pure clay there enter into these earths irregular and overturned masses in which clay, marl and sand may be found, mixed in various proportions and without continuity.

2. The impermeable earths proper, including only those that can neither be traversed nor penetrated by water, and in which little else can be found than certain compact and seamless rocks or earths.

Action of Water on Clayey Masses in Place.—Clayey earths are the only ones of which the presence may give rise to serious slips. These accidents present different characteristics, according to the nature of the various overlying earths.

When a clayey mass is in the neighborhood of the surface of the ground, it is always covered with a layer of mould or vegetable earth, which belongs to the list of slightly permeable earths. This layer may rest immediately on the clayey mass; but frequently it is separated therefrom by a layer, generally of slight thickness, of gravel or of coarse pure sand, which is eminently permeable. In this case the rain water falling on the surface of the ground, after passing through the seams of the slightly permeable layer, reaches the eminently permeable layer, is there confined and forms a thin

sheet that follows the general surface slope of the clayey mass. If this flow be easy, the water does not remain in the upper layer. If it be difficult, it may rest there and rise to a certain height in the seams. But if the dampness and rains be not too persistent it disappears quite rapidly, a part evaporating through the seams and a part flowing off through the eminently permeable layer.

The sheet of water existing in this layer protects the clayey mass by always keeping the surface damp. Deep seams could only be opened after long dry spells, if the sheet of water were dried up and remained long dry.

A marked sheet of water at the surface of separation between the slightly permeable earth and the clayey mass, only exists where there is a layer of eminently permeable earth. If this latter layer do not exist the water remains in the seams of the slightly permeable earth without flowing on the surface of the clayey mass. It only disappears by evaporation; but then dryness is propagated through the slightly permeable earth and acts on the clayey mass by causing seams to be opened in it. Water coming after this, having passed through the seams of the slightly permeable earth, penetrates into the seams of the argillaceous mass and causes the clay to swell. The seams are closed and the mass again becomes impermeable. The water then remains in the seams of the upper layer, its level in them rises, reaching even the surface of the ground, and as the earth can only be drained by evaporation it necessarily remains damp for a considerable time. On the other hand, the stagnant water reacts on the clayey mass, the hydrostatic pressure developed by its increased height may keep a certain number of seams open, make them open still further, and make the water penetrate deeper.

In this way the water circulates within the seams of the clayey mass. It may rest more particularly in the veins of sand contained therein, and even form sheets there. But these veins of sand are not very continuous as a rule; the sand itself is more or less mixed with clay and therefore is not very permeable, so that as a rule the water remains there without circulating.

If a cut be made in earths thus arranged and there exist on the clay a layer of eminently permeable earth, the sheet of water that it contains crops out on the slope, over which the water will flow. If there be no layer of eminently permeable earth, no water is seen to flow in the line of separation between the clay, and the

slightly permeable earth does not seem to be more damp than the rest of the slope.

In the clayey mass a little intermittent oozing out of water is noticed. This is due to the setting free of the water therein confined. This oozing out of water takes place particularly in the veins of sand, but it also occurs where the slope has cut a seam of the clay. Generally this oozing stops after a certain time and does not appear again, because the seams by which it was supplied are closed or are no longer in communication with those that a new dry spell has opened at the surface of the mass.

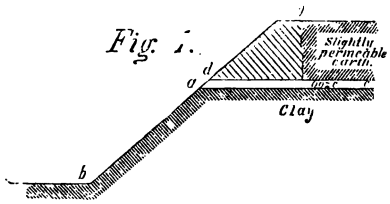
These oozings that may appear at the surface of slopes in the clayey mass, are those that M. de Sazilly mentions as difficult to observe and only to be verified by a suitable temperature, by visiting the slopes early in the morning or by covering them with a very thin layer of sand.

II.—THEORY OF SLIPS.

The slips or cavings-in caused by the presence of clay, take place in the slopes of cuts and fills. It is very important to distinguish between these two cases. On account of not having done so MM. Collin and Sazilly have certainly been led astray. They have applied to the slopes of cuts a theory deduced almost entirely from observations made on the slopes of fills, which theory, not being quite exact for the latter, is certainly not so for the former.

Slips in the Slopes of Cuts.—We shall first consider the slopes of cuts. The earth in which they are made almost always presents one of the two appearances above indicated : a mass of clay surmounted by a layer of slightly permeable earth, with or without the interposition of a layer of eminently permeable earth.

Fig. 1.



Case in which there Exists a Sheet of Water.—In the first case —shown in fig. 1—the layer of eminently permeable earth in which the water settles, is generally quite thin. After making the cut the ooze that it contains is laid bare and the water flows down the lower clayey earth following the part *a b* of the slope. It carries

away the pieces of the layer of sand and gravel *a c*, through which it filters. Near the opening *a* of the orifice is formed a small hollow which makes the point *a d e* of the upper earth cave in. To this first slip are added others, and a little mound will inevitably form at *a*, which will stop the flow. If the pressure be sufficiently great the water may rise to a certain height in the seams of the upper earth, but that will rarely happen. As a rule the pressure in the eminently permeable earth is small; besides if the weather be dry there can be formed but little under the action of this pressure except a series of small successive slips, after which there is formed on the slope a heap of earth that is saturated by the water from the ooze. Supposing, as does M. de Sazilly, that the phenomenon becomes complicated by the action of freezing and thawing and by that of atmospheric agents on the clay, the accident may be aggravated. But if this aggravation were to be only the consequence of the softening of the clay and of its crushing under the weight of the upper earth, it will take place slowly and gradually.

Another force comes in to completely modify the conditions of equilibrium—this is the hydrostatic pressure.

When the surface water from an abundant or long continued rain passes through the slightly permeable earth, it comes to the layer *a c* (fig. 1). If the flow at *a* be assured, it will not remain long in the slightly permeable earth and cannot rise to any great height therein. But if the opening be closed the water rises rapidly and develops the hydrostatic pressure. On the other hand the seams lessen the cohesion of the slightly permeable earth and form true pre-existing surfaces of separation along which the mass tends to split. Finally, the resistance to sliding along *a c* is diminished, as much by the surface softening of the clay as by the under pressure caused by the water, so that a time comes when the hydrostatic pressure having become greater than the resistances, causes the beginning of a movement that shows itself by the formation of fissures at the top of the slope, at some point as *g*, and by the production of a bulge in the slope in the neighborhood of the line of the ooze.

After these first slips the movement almost always stops, and, if the weather be dry, the new condition of equilibrium may be prolonged. The movement may begin again without more rain; but it does not generally start until more falls and almost immediately afterwards. The movement re-begun almost always continues with-

out interruption. After the first movement the flow of the sheet of water is generally stopped, and the clay underneath the mass that has started, softens the more easily as it must have felt the beginning of breaking up. Then it is, in the second period of the movement, that the action of the weight is felt. The weight of the upper mass, that has already started, whether it receive a new impulse from the hydrostatic pressure or not, bears on the part of the clayey mass softened by the water, crushes it and forms the bright and soapy sliding surface that has been noticed by all observers.

Thus, in our opinion, the beginning of the movement would be caused exclusively by the hydrostatic pressure, and it would only be after the first movement, made evident by fissures and a bulge in the slope, that the softening of the clay takes place. It will only be in the second period of the movement that the crushing of the clay takes part, but the action of the hydrostatic pressure would still be left.

Agreement between the Explanation and the Circumstances that Accompany Slips.—This explanation of the slips caused under these conditions agrees perfectly with all the circumstances that accompany them.

It takes into account the considerable slips that happen shortly after making the cuts, and before there has been time for the clay to become softened.

It also accounts for the stoppage that comes after the formation of the fissures, and this circumstance does not agree at all with M. de Sazilly's theory.

If the movement came solely from the crushing of the clay, it would, after being once begun, continue without interruption. The soft clay pushed toward the vacant space, meets no new resistance after the movement has begun.

The resistances, coming either from cohesion or from the sliding friction, are less in the moment succeeding the beginning of the movement than in that preceding. Hence there is no reason for the movement stopping. In any case, the stop could not be for long, because the first displacement makes the softening more active, without there being any need of fresh rain.

This is not the case if the hydrostatic pressure be the main active force in determining the beginning of the movement. The formation of fissures is only the opening of the seams under the action of this pressure. Now, the immediate consequence of the

opening of the seams is to lower the level of the water therein. If no new surface water come to fill up the seams, the condition of equilibrium following the first movement may last for even a considerable time. The movement can only be started again by fresh rains, but then it will almost always have to follow them immediately.

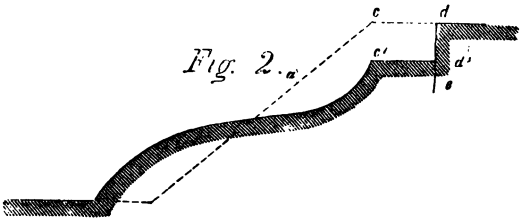


Fig. 2.

Another circumstance that does not agree with M. de Sazilly's theory, is the position taken, as a rule, by the upper part of the slipping mass *a c d e* (fig. 2), after the movement has occurred. This mass in falling almost always keeps its general shape and is not much broken up. The surface *c d* takes a new position *c' d'* almost always parallel to its first position. Sometimes it even has a slope toward the still standing earth, as shown in fig. 3.

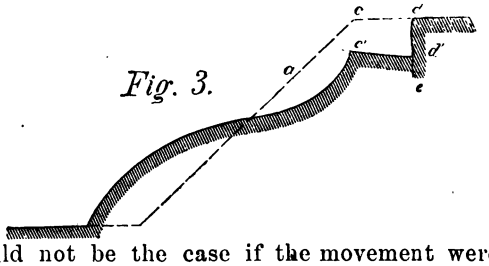


Fig. 3.

This should not be the case if the movement were the consequence of the crushing of the clay alone. In fact the softening must be greater near the slope than a little way back. It must take place parallel to a curve *f g h* (fig. 4), so that the mass below

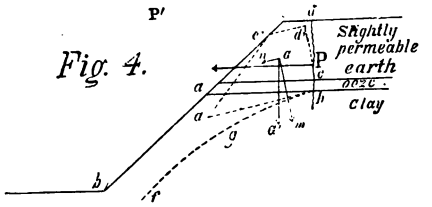


Fig. 4.

f g h retains more solidity than the mass above. Again, the side

c d offers a certain resistance to sliding, which opposes a vertical motion of translation of the mass *a c d e*. Finally, the weight of this mass, of which the resultant is a force G G′, applied at the centre of gravity G, can only act to produce the movement by a component G *n*, parallel to general direction of the curve *f g h*. Now it is easy to see that this action, in dragging down the mass *a c d e*, should make it lean toward the cut.

The hydrostatic pressure, on the contrary, supposing it to act only in the seam *c d*, has a resultant P P′. This force, causing the separation along *c d*, allows the vertical motion of translation, if the clay be sufficiently soft; and, in the contrary case, has the very natural effect of making the mass *a c d e* take a reverse slope. This effect is still more certainly caused if we consider the hydrostatic pressure as also acting at the base *a c*.

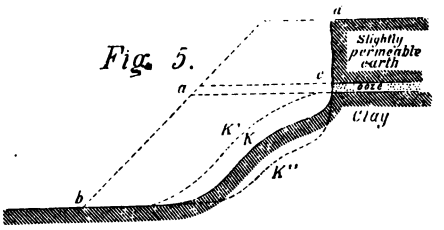
The shape of the line of separation, that is of the intersection of the surface of intersection by a vertical plane in the direction of the motion, has a special interest. In the case that we are studying, that of a slip in the slope of a cut where exists an ooze, we never have a line of continuous curvature and cycloidal in shape such as mentioned by M. Collin. The line of separation always presents the following characteristics very clearly:

Throughout the entire height of the slightly permeable earth it is sensibly vertical as shown at *c d* (fig. 5), and sometimes it even overhangs. This part of the wall when laid bare never shows any traces of rubbing, and is not continuous and smooth. It has sometimes the bright appearance occasionally noticed on the sides of seams, which is due to the passage and stay of water. It is only below the ooze that the line of separation becomes curved and the side smooth with traces of rubbing. The curvature of this lower part of the line is never continuous. Below the ooze it almost always presents a bend like that shown at *c* K *b* in fig. 5. The convex part of the curve recalls exactly, by its shape and position, the curve *f g h* (fig. 4) drawn to show the direction in which the softening is propagated. The beginning of the convex part is more or less near the ooze. Sometimes it is just below, and the line takes the shape *c* K′ *b*. At others, on the contrary, the convexity is much lessened, and the curvature of the line approaches continuity, as shown in *c* K″ *b*.

We have been the more struck by the constant existence of this inflection, in all the slips that we have noticed, because it seems to

contradict the observations made by M. Collin; but the contradiction is only apparent. All the curves of slips prepared by M. Collin himself were produced in the slopes of fills. He only mentions one line of a slip in the slope of a cut, which appears to have been drawn with some precision, that of the slip in the Hesse cut. Now this line shows an inflection, little marked, it is true, but which would be still more so if the upper element of the line of separa-

Fig. 5.



tion were shown vertical, as it must have been when the movement took place. M. Collin, whom this inflection did not escape, attributes it to the succession of two slips; but it is hard to receive this explanation, because the mass of earth existing between the first cycloid and the second is much too small to have moved by itself. Besides this, the information given to M. Collin by various engineers, in the shape of the lines of slips in the slopes of cuts, are far from confirming the continuity of the curve. To show this we shall confine ourselves to giving here an excerpt from a letter of M. Charie-Marsaines, as found in a note at the end of M. Collin's article:

"The lines along which slips take place are generally very much broken; almost all show in their upper part a sensibly straight wall; it is only at the lower part that they have a gentle curve. There are but a few parts very much softened by water, where I have noticed continuous curves without inflection, like those you have drawn. . . . The slips never occurred instantaneously; they were always announced by breaks on top of the ground, and greater or less portions being detached from the mass that was ready to slide. The surface along which the slip took place was quite often continuous and soapy, but not always."

This description is far from giving an idea of the cycloidal shape at which M. Collin stopped. It agrees better with the one we have observed. If the agreement be not complete, it is because M. Charie-Marsaines has not distinguished between the case where a sheet of water exists and where it does not. When the second

case is considered, the explanation of the discrepancies that seem to exist between M. Charie-Marsaines's observations and ours will be given.

The fact that the beginning of the movement is not due to the softening of the clay is also confirmed by the efficacy of the method pointed out by M. de Sazilly to prevent slips in slopes where a sheet of water is present. We know that this method is to construct a masonry gutter at the point *a* (fig. 1) to collect the water and protect the part *a b* of the slope from its action. This gutter does not prevent the water from acting on the surface *a c* of the clayey mass, and the softening below this surface can take place as well with as without the gutter. Hence there is no reason why the gutter should prevent the movements that would be the consequence of the softening of the clay; it can only delay them. If it be objected that the softening is no longer possible because the surface *a c* of the clay is protected from atmospheric influences, we are then obliged to admit that degradations never take place except at the surface of the slope; that in no case can an unexpected movement of the mass happen, and that accidents of any importance can only come after a necessarily long time.

Case in which No Sheet of Water is Present.—Let us now come to the case where the slightly permeable earth lies immediately on the clayey mass. The sliding at the surface of this mass can no longer be caused except in very rare cases, because the lessening of the friction along this surface can only follow from the surface softening of the clay, without being increased, as in the preceding case, by the under pressure exerted in the layer of eminently permeable earth. The important part of the phenomenon takes place in the interior of the clayey mass. The absence of the sheet of water assists the formation of seams in the surface of the clayey mass, at the same time that the standing of the water in the slightly permeable earth gives rise to the hydrostatic pressure in these seams. The elasticity of the clayey mass being destroyed by opening the cut, either a general swelling or a break along a given seam may be caused. Hence we have two kinds of accidents.

The enlargement may itself involve the immediate disintegration of the mass; it may be produced, on the contrary, without disintegration being apparent, and be propagated without anything showing it outside until it is sufficiently complete to cause a movement at the bottom. The first kind of accident is thus presented under two different forms.

Case of Immediate Disintegration.—When the enlargement involves immediate disintegration, the movement begins at the surface and is at once manifested by the sliding of small masses of clay. These masses being detached from the slope are more or less disintegrated at the instant that the movement is produced, but they are never in a fluid condition. If they be at once removed, the surface of separation has nowhere the smooth, soapy appearance caused by friction. It presents the bright appearance of the sides of seams. Hence it is not a slide that is produced, but a true breaking off. It is only when the detached earth has been left for a certain time in place and been softened by rains, that it presents fluid parts and slides are produced; and these slides are still due rather to the thrust of the water accumulating in the voids of the disintegrated earth than to the giving way of this earth. Accidents of this kind, visible so soon as they take place, are propagated successively, and it is only in the long run that they assume a character to cause apprehension.

Movement at the Bottom after a Latent Disintegration.—If the enlargement be not accompanied by immediate disintegration, the latter takes place without any outside sign. There is then formed in the clayey earth a series of seams into which the water enters with greater ease. The enlargement stops near the bottom of the cut. A sliding takes place at this level as a consequence of the enlargement of the upper mass, and the water, reaching this point through the seams of the distended mass, further lessens the resistance to friction. A movement then comes when this resistance is too weak to balance the hydrostatic pressure of the water remaining in the seams, and a movement of the mass is caused.

At the moment the movement begins, any considerable quantity of fluid clay is rarely found in the overturned mass. The softening is produced when the water afterwards penetrates the disintegrated clayey earth. The delay that necessarily takes place in removing the moving earth causes an error on this point, and has alone been able to give rise to the belief that the movement was due to the crushing of the clay. The beginning of the movement is still shown by cracks in the neighborhood of the crest of the slope; but these fissures are much more numerous than in the case of a sheet of water, and the overturned mass is much more disintegrated. The movement no longer takes place continuously. It has intermittent periods corresponding to the alternations of rain and

dryness, but it presents no such marked pause. The upper part of the moving mass still comes down parallel to itself or leaning toward the solid earth.

The line of separation is still sensibly vertical, and even slightly overhanging in the upper part corresponding to the slightly permeable earth. In the clay it inclines towards and approaches the direction of the slope, and near the bottom it becomes horizontal. In its general shape it may remind one of the cycloid, but it is far from being a continuous curve. The lowest point of the line of separation is generally at the level of the bottom of the cut; still it is sometimes above and sometimes even below this level. It is only at nearly the lowest part that the surface of separation presents the polished and soapy appearance of a sliding surface. In its upper part, to a point but little above the bottom of the cut, it has nothing more than the appearance of a surface of breakage; it has its roughness and irregularities.

Everything then seems still to show that the crushing of the clay is no more the original cause of the accident in this case than in the others. The little damp clay found in the overturned mass when the movement begins, the stop in the progress of the slip, the direction in which it is caused, the appearance of the surface of separation, show the exclusive action of hydrostatic pressure.

Movement Due to the Rupture along a Seam.—This conclusion is still more strongly forced upon us in the last class of accidents that we have to mention, that which is caused by a break along a given seam.

Besides the small and discontinuous seams enclosed in clayey masses, others that cross them to a great distance are often found. This kind of seam has already been pointed out by M. de Sazilly, who called them principal cleavage planes at the same time that he called the others secondary cleavage planes. These principal seams may undoubtedly disappear, as the others, under the influence of the reactions of the mass, but they are certainly more persistent. They generally have a direction approaching the vertical, doubtless because this direction is the most favorable to their formation and preservation.

When a seam of this kind is a little in rear of the crest of the slope and in a direction approaching that of the cut, the water that filters in develops a pressure that tends to make it open more. The extension may take place in length or in depth. In length the

seam, as it extends, approaches the cut, so as to limit the size of the block separated from the mass. In depth it extends in the direction where least resistance is found. If the slope be intersected by a vertical plane perpendicular to the axis of the cut, the line of least resistance in this section starting from a given point behind the crest of the slope, will at first be nearly vertical, then will become nearly parallel to the surface of the slope, afterwards, being headed off by the resistance of the ground at the bottom of the cut, it will take a horizontal direction. This line of least resistance must then necessarily present a general shape reminding us of the cycloid or some similar curve.

The seam is propagated along a curve of this kind, and as it does so the extent of the surface along which complete cohesion still exists is lessened at the same time that the hydrostatic pressure is increased. A time comes when the latter is greater than the bottom and lateral resistances. The partly detached block of earth is then wholly separated and starts toward the cut. The movement takes place slowly and irregularly, increasing after rains, stopping entirely during dry weather, and continues until the moving block is disintegrated by the action of atmospheric influences.

Example of a Movement of this Sort.—An opportunity was had for observing a movement of this kind in one of the slopes of the ditch of Fort Stains. To stop the movement of this block it was divided normally to the axis of the ditch, by little trenches in which spurs of dry stone were placed. The trenches thus opened as far as the surface of separation, allowed the phenomenon to be studied before the moving mass was disintegrated, and gave very valuable indications for determining the causes thereof. On the outside the movement was shown by the formation of a crack in the earth behind the crest of the slope, by a moving forward of the foot of the slope and a slight falling back at the top, and by the very marked upheaval of the bottom of the ditch in front of the moving mass.

On the inside this mass was entirely solid. The line of separation had the general shape mentioned above, recalling sufficiently that of a cycloid or similar curve; but the continuity of its different elements was far from being perfect.

The width of the opening along which the separation had taken place was different at different points of the curve. It was nothing

at the top where the line of separation was scarcely visible. At this part a pressure seemed to have been brought to bear by the moving upon the standing parts. In the middle part, on the contrary, the separation was very marked, and there were points where the arm could be thrust down into the gaping fissure. At the bottom the line of separation was hard to trace. However, in excavating, traces were found of the smooth, soapy surfaces on which the slide took place, and this surface extended to 6.50 feet below the bottom of the ditch. Nowhere was soft clay found. In the middle part no traces of sliding were found on the face of the fissure.

All the circumstances point out a horizontal displacement of the moving mass, accompanied by a motion of rotation causing a falling to the rear, but without any sensible vertical displacement of the centre of gravity. Now, a movement of this kind cannot be caused by the sole action of the weight of the mass of earth. The work of this force is almost zero, since the centre of gravity has not moved down, so that it could not overcome the resistance offered by cohesion and friction, nor could it cause the crushing and upheaval of the earth at the bottom of the ditch. We must suppose some other active force than gravity, and hydrostatic pressure, by the way in which it acts, explains in the most complete way the movement that took place. The resultant of this pressure has a horizontal component that determines the horizontal motion of translation. Its point of application is below the centre of gravity of the mass, which explains the motion of rotation about this centre of gravity. The vertical component of the hydrostatic pressure acting upward from beneath, raises the mass and diminishes the friction on the surface of separation, at the same time that the existence of the seam in which it takes place renders almost zero the cohesion between the moving and standing earth.

The movement in question had begun in the winter of 1876 and 1877, and was completely stopped during the summer of 1877. The galleries begun during this summer, had reached the line of separation before autumn, and the movement has not since started again, in spite of the return of winter. This stopping could not be explained if the weight and crushing of the clay were the only causes of the movement, because the effect of opening the galleries was rather to facilitate the softening of the clay at the foot of the mass. On the contrary it is explained if the hydrostatic pressure be the cause of the movement, because the galleries prevented the water

from accumulating in the open seam and bringing a pressure to bear therein.

A last circumstance that is worth mentioning is, that the general movement of the mass did not take place in a direction exactly normal to the axis of the ditch. This fact seems to us to confirm the pre-existence of a very extensive seam. If this seam had been caused after the opening of the ditch, it would have been symmetrical with a right line perpendicular to the axis of the ditch, and the movement would have taken place in a direction normal to the ditch.

From the direction that the movement really took, we must necessarily conclude that the seam which started it was oblique to the axis of the ditch, and the pre-existence of the seam follows from this inclination.

Slips in the Slopes of Fills.—The examination that we have just made of the circumstances attending the movements in the slopes of cuts in clay, seems to us to show that these movements are not due, as heretofore believed, to the action of the weight of the upper parts crushing the softened clay, but to the hydrostatic pressure acting in the seams that exist or are made in the clayey masses. This is not quite the case in the slopes of fills, which we shall now consider.

When an embankment is made, the materials used are made up of overlying fragments of greater or less size. Under the weight of the mass, the fill may undergo a first species of settling coming from the changes made by pressure in the relative position of the fragments. The smaller penetrate the voids between the larger, and finally a condition of equilibrium resulting from a certain arrangement of fragments is produced, there still being left numerous voids through which water may circulate.

If, under the weight they have to bear or under the action of water, the various fragments are divided, the consequence of this division is to further reduce the voids existing in the mass, and a new kind of settling follows, which continues until all the fragments have become indivisible. After this second settling, the consistency of the fill approaches with time that of the unbroken earth, which at first it in no wise resembled. When the fill is formed of indivisible fragments of considerable size, its consistency becomes that of an eminently permeable earth. When the indivisible fragments are smaller, if the earth that forms the fill contains but

little or no clay, the mass has a consistency analogous to that of the slightly permeable soils. Seams form therein and give an easy escape to the water. In both cases there are no accidents to be feared, provided that the slopes have not been made too steep, and that they have been sufficiently protected against surface erosion.

Breaking the clods, settling by ramming or rolling, have for their effect a more rapid taking by the ground of its final equilibrium and diminishing the settling due to each of the two causes that we have just mentioned.

When the fill is composed of clayey earths, the fragments forming it may be reduced to very fine indivisible particles; but this reduction is less easily made on account of the cohesion of the clay, and the settling takes place more slowly.

Slips having very different characteristics may then be produced, according as they happen during or after the period of settling.

Slips During the Period of Settling.—During the period of settling, water may penetrate the clayey mass more easily and more abundantly than it would unbroken earth, because it no longer finds a passage way through the seams alone, but also through the voids existing between the particles. The mass is then more easily and quickly disintegrated; it tends to take the consistency of a more or less liquid mud, and this disintegration takes place mainly at the base of the fill where the weight is greatest, and where the water does not accumulate. We can see that, in these conditions, the crushing of the soft clay under the weight of the upper masses of earth, is enough to explain the movements at the bottom without any intervention of the hydrostatic pressure being necessary. Still it seems to us that this last force undoubtedly plays some part. Water may often be seen lying in fissures made at the top of the slope after the earth has settled. This water exerts on the sides of these fissures a pressure that must necessarily assist in causing the movement. In any event, however, the destruction of the cohesion of the clay by the contact of water and the weight of the upper earth have, in the case of fills and during the period of settling, the preponderance assigned to them by MM. Collin and Sazilly.

When a movement takes place under these conditions the line of sliding is the continuous curve analogous to a cycloid that M. Collin has traced in a great number of cases. The greater part of the sliding surface is smooth and soapy, and shows traces of rubbing.

The movement once begun generally continues without interruption, and without there being noticed that constant and sometimes prolonged stoppage that follows the formation of fissures at the top of the slopes of cuts. Besides, the sliding mass is almost always entirely broken up ; it falls forward and never back.

Slips After the Period of Settling.—After the period of settling, that is, when the fragments are all reduced to indivisible particles, the fill takes the consistency of unbroken clayey earth. It takes it very quickly if it be well rammed. We have noticed this fact in an embankment made around the buried abutments of an upper passage. A year after it was made it could not be distinguished from the adjacent unbroken earth composed of the same elements. When a clayey fill has reached this point, the slips that may take place do not differ from those in the slopes of cuts.

But before the settling is complete and the fill has reached the consistency of unbroken earth, it passes through intermediate stages in which its cohesion continues to increase, so that according to the time at which they occur these slips may appear with characteristics more or less approaching those in the slopes of cuts.

Conclusions.—To sum up, slips in the slopes of fills do not have the same characteristics as those in cuts. In the former the predominant causes may be, the softening of the clay as the passive cause, and the weight of the earth as the active cause. In the latter, on the contrary, the predominant, if not the sole causes, are the lack of cohesion, resulting from the presence of seams in the mass, and the hydrostatic pressure in the seams. These two sets of causes may work together to cause the movement, especially in an old fill of which the consistency approaches that of unbroken earth, or in a cut previously disintegrated by the swelling that is the consequence of opening a trench. Their actions may be simultaneous, but they may be consecutive, as happens in the slope of a fill traversed by a sheet of water, in which the movement begun by the hydrostatic pressure is finished by the crushing of the clay.

III.—MEANS OF PREVENTING SLIPS.

Slopes of Cuts.—We must now see what indication this theory may give on the subject of the means to be employed to prevent accidents, and we shall first consider the slopes of cuts.

The general cause of slips being the action of water on the clayey

mass, the most certain preventive would be to remove them completely from this action ; but that is never possible. Hence we can only seek to lessen its effects. Now what renders the action of water specially hurtful, is not so much the surface contact, however prolonged that may be, as its penetration and stay in the mass.

What facilitates this penetration is the periodicity of the contact, the stagnation of the water at the surface and the rising of the level which it attains. When a sheet of water flows constantly over the surface of a clayey mass, it keeps the top of this mass constantly wet, which prevents its contracting and making seams. If the flow of water be so assured as to exert no pressure on the clay, we may consider its introduction into the mass as almost impossible.

If, on the contrary, the presence of the water at the surface of the clayey mass be not continued, and the clay be submitted to alternations of dryness and dampness, the dryness tends to open these seams. If the water that then follows remain standing and rise to a certain height above the surface of the clayey mass, a hydrostatic pressure is developed in the seams, tending to keep them open, to open them more, and, consequently, to make the water penetrate to a greater depth. From this it follows that, if there exist on top of the clay a layer of eminently permeable earth, in which a sheet of water may circulate freely, the penetration of the water must be, so to speak, nothing, and the stability of the clayey mass assured.

The chances for slips begin if the sheet be subject to drying up, but they are still small if the flow be well assured through the eminently permeable layer.

These slips are to be feared if the flow do not take place through the eminently permeable layer, or if this layer do not exist, and, consequently, the level of the water may rise in the slightly permeable earth.

When a certain quantity of water has penetrated a clayey mass, it may move therein. To this end it follows the seams that traverse the mass or that are formed there, and may condense in the more permeable parts. The water that has thus penetrated the seams exerts a pressure which is the principal cause of slips, and we must try to suppress this pressure by assisting as much as possible the passing off of the water.

Hence the end that we must first propose is to prevent the water from penetrating into the clayey mass and to facilitate the passing off of that which has already gone in.

Means for Preventing Penetration.—The water may penetrate through the upper surface of the mass, which is covered by a more or less permeable earth, and by the surface of the slope laid bare in making the cut.

Work to be Done at the Surface of the Ground.—At the upper surface, the water comes through the layer of slightly permeable earth that overlies it. The first thing to be done is to prevent, so far as possible, the water from coming through this earth, and this is what is done by ensuring the surface flow at the edges of the cut. Hence the usefulness of top side ditches, provided that the flow of the water be perfectly sure, for could it remain standing, a result the very reverse of what we expect may happen.

The reverse slopes by which the direct flow of the water on the slopes is prevented, have really no other use than to prevent gullies forming in the sloping face. Were they to have as a result the bringing of the water together at certain points, at some distance in rear of the crests, they would assist penetration and increase the chances of a bottom movement in the clayey mass. Hence reverse slopes should only be established under the condition of perfectly assuring in another direction the flow of the water which they stop.

In general terms, we should first try to ensure an easy flow for the surface water that reaches the edge of the cut and prevent its remaining there. All methods used will be good if they attain this end. They may be varied to suit local causes, but the result to be had being perfectly determined, it will always be easy to obtain it with a little care and attention.

Protection of the Top Surface of the Clayey Mass.—Whatever we do, however, it is always impossible to entirely prevent water from penetrating the slightly permeable earth and reaching the surface of the clayey mass. If there be on this surface a layer of eminently permeable earth with an inclination toward the cut, the water soon reaches the slope. If the inclination be away from the cut, the water flows into the ground. If the flow were not easy it would back up in the eminently permeable layer, and might flow over on the slope; but the height to which it would rise in the slightly permeable upper earth would be limited at the level of the overflow from the eminently permeable layer to the surface of the slope.

To insure the stability of the clayey mass in both cases, it will suffice to keep up an easy escape for the water where it flows out on

the slope, and this is what the little drains devised by M. de Sazilly do in the most thorough way. The broken stone with which they are filled served the double purpose of making a filter that prevents particles of the eminently permeable earth from being carried away, and of sustaining the edge of the slightly permeable earth, of which the caving-in might obstruct the line of flow. Hence the efficacy of these drains is not due, as M. de Sazilly thought, to their shielding from contact with the water the clayey mass apparent in the slope below the ooze, but to their preventing the accumulation of water in the slightly permeable upper earth. In this respect, at least, their efficacy is complete.

If there be no layer of eminently permeable earth between the clayey mass and the slightly permeable earth, the passing away of the water does not take place through the latter, and there is no ooze marked on the slope. The establishment of a drain at the upper limit of the clay can have but a narrow field of usefulness. It can act but to a very small distance in the slightly permeable earth, and cannot prevent the water from standing therein. In this case M. de Sazilly's method is not sufficient to prevent slips, and we must necessarily seek another.

Protection of the Slope.—To prevent water entering the surface of the slope, it should first be protected from atmospheric influences which cause seams to form, and this is accomplished by means of a revetment. The flow of the water passing through this revetment must be assured, and this cannot be done better than by forming on the clayey mass itself an eminently permeable layer. Without this layer the revetment may do more harm than good. If it be of sod or of vegetable earth and placed immediately on the clay, it has much the same effect as the slightly permeable earth at the top of the mass. The same is true of a stone revetment, the joints of which act like seams in which the water accumulates without being able to flow off easily on account of the joints being broken.

Hence it is indispensable that the revetment of vegetable earth, of sod or of stone, should be separated from the clayey mass by means of a filtering layer, at the bottom of which the water finds an easy flow out. This filtering layer is necessary in all cases, because there is no clayey mass that can be called perfectly impermeable, and which may not be penetrated to a certain extent by water.

Means of Ensuring the Passing off of the Water.—The water

that penetrates the clayey mass can only pass off at the surface of the slope. This passage is effectively made by oozing out through discontinuous veins of sand or at the mouth of seams. This passage may be stopped by surface slips or by frost that makes the surface of the slope perfectly impermeable. But the revetment with a filtering layer is sufficient to prevent these accidents from happening. If there existed in the clayey mass a well marked ooze with a constant flow of water, we should not hesitate to collect it in a gutter; but the filtering layer seems to be enough for the few, undefined intermittent tricklings that are generally found.

General View of the System of Protection in the Case of a Sheet of Water.—Thus, in a clayey mass at the surface of which exists an eminently permeable layer, constantly traversed by a sheet of water, we are almost absolutely sure of preventing slips, by ensuring the flow of the water in a drain on M. de Sazilly's system, and by covering the clayey earth with a revetment having a filtering layer under it. We do not think that we need even worry about the occasional stoppage of the drain, because if that occur the water would overflow into the filtering layer. The only thing to be feared is the obstruction of the sheet, but this is not possible with a well made drain.

The safety is less when the eminently permeable layer is not constantly traversed by a sheet of water, but in this case we do not think there is any accident to be feared, if the flow of the water that may enter the eminently permeable layer be assured.

Case in which No Sheet of Water Exists.—The conditions are no longer the same when there is no eminently permeable layer on the surface of the clayey earth. In this case, the surface works made on the slope, such as gutters and filtering layers, cannot drain the earth sufficiently to do away with the pressure of the water inside. The drainage would have to be carried to the interior of the mass; but all deep drainage, such for example as would be obtained by spurs of dry stones, would have the effect of aiding enlargement and consequently disintegration. The remedy would have fewer advantages than disadvantages. It is better, we think, to avoid everything that might result in dividing the mass, and limit ourselves to a surface drainage, seeking by other means to prevent the formation of any enlargement. This end will be reached by finding those conditions where is the least chance for its forming and then opposing to the thrust of the earth a resist-

ance that will, so far as possible, take the place of that exerted by the earth in the cut.

Inclination to be Given to the Slopes.—It is easy to understand that a vertical slope is the one giving the most favorable conditions for causing a swelling, and that one very nearly horizontal gives the least. But as the inclination lessens, the penetration of the mass from the surface becomes more easy and the possibility of the water on the inside passing off becomes less. Hence there is probably some limit beyond which the inclination of the slope should not be reduced, so that we cannot hope to protect ourselves from slips by simply reducing the inclination. Besides, this reduction increases the volume of the excavation and consequently the expense. In selecting an inclination we must consider local causes and cost, without trying to avoid the necessity of making a resistance to oppose the enlargement of the earth. For this resistance a revetment is required.

Quick Execution of Protecting Works.—We must first remark, that a much less resistance is required to avoid the formation of a small seam than to prevent a deep seam already existing from opening. In other words, it is easier to avoid slips in ground that is not yet enlarged than in that where the enlargement already exists.

Hence it is of the greatest importance to build the revetments before the earth shall have had time to swell, that is to say, so soon as the cut shall have been made and the slopes graded. Especially must not graded slopes be allowed to stand through the winter without revetments, because it is during this season that the swelling is most apt to occur. If the cut cannot be finished in one season, the slightly permeable upper earth and the centre of the clayey mass should be removed during the first season, leaving until the second to finish the cut, grade the slopes, and build the revetment. If the work cannot be done thus, only a small length of the cut should be finished at a time to its full width, in proportion as the revetment can be finished.

Resistance of the Revetment.—The revetment resists enlargement by its weight and stiffness. In a vertical slope its stiffness only acts. If the slope have an inclination, the revetment also acts by its weight, and this action is more effective as the inclination of the slope to the horizon is less, because on the one hand the component of the weight normal to the slope increases as the inclination dimin-

ishes, and the same holds good, on the other hand, for the development and consequently for the total mass of the revetment for the same thickness. From this standpoint, therefore, it is well to reduce the inclination of the slope, but this advantage is only acquired at an increase of cost.

The weight of the revetment depends on its thickness and on the density of the material of which it is made; its stiffness depends on the nature of the material and the care used in building. For a given thickness a dry stone revetment is better than one of sod or vegetable earth, because its density and stiffness are greater. The stone revetment is the more effective as the stones used are more carefully trimmed. It has also the advantage of completely avoiding the obstruction of the filtering layer placed beneath it, on the surface of the clay, an obstruction easily produced in the case of a revetment of sod or of vegetable earth, by the introduction of earth or roots into the voids of the filtering layer.

Summary of the Rules to be Followed for Protecting the Slopes of Cuts.—To sum up, to prevent slips in the slopes of excavations in clay, we must—

1. Ensure an easy escape for the surface water coming in the neighborhood of the crest of the slope.

2. Give a proper inclination to the slope.

3. Avoid all work that may divide the clayey mass and assist its swelling.

4. Collect in drains of M. de Sazilly's system all well defined oozings found at the surface or in the interior of the clayey mass.

5. Make, on the open part of the slope in the clayey mass, a filtering layer giving an easy flow to the water which shall always find a permanent outlet at the bottom.

6. Cover this same part of the slope with a heavy and stiff revetment.

7. Perform all this work of draining and reveting so soon as the trench is opened, and especially do not let a winter pass over the graded slopes.

The greater part of these operations have already been pointed out by M. de Sazilly. They were suggested to him rather by his instinct as a constructor than by his deductions from a theory that was neither sufficiently precise nor thoroughly exact. The only new points that we mention are the necessity of avoiding all work that may divide the clayey mass, of making in all cases a filtering

layer on the surface of the clay slope, and of giving strength and stiffness to the revetment. On the other hand, we do not think it necessary to multiply drains to the extent recommended by M. de Sazilly, and we think it sufficient to put them where there is a well defined and continuous layer of eminently permeable soil, without placing them at ill defined, discontinuous and intermittent oozings found in the interior of the clayey mass.

A doubt may be raised as to whether these will suffice to prevent accidents due to a break along an extended pre-existing seam.

We reply by saying, that in the first place these accidents are rare, and that their production is an improbability that must not be considered unless we wish to go to considerable expense that, as a rule, is useless. But we think that, as a rule, the works that we mention will be sufficient to prevent them. It is a question of weight and stiffness in the revetment. These works will only be insufficient in exceptional cases, in which repressive and not preventive means should be employed, as when the swelling of the clay has taken place.

Application of these Rules.—These principles have been successfully applied in two cuts on the railroad from Epinay to Luzarches, made in the clays overlying the gypsum of the basin of Paris, where an important slip occurred during the progress of the earth work. We shall briefly mention the methods adopted, pointing out, at the same time, the limits within which it seems well to remain in the application of the preceding rules.

In order not to make new purchases of land, and not to increase the volume of earth to be handled, the sides were kept at the angle of 45°, as originally intended. We think that this is the steepest slope that should be adopted, but we do not think it necessary to take a less slope than 1 on 1.5. Applying the principles laid down by M. de Sazilly, drains were first used in great number, placing them wherever any sepage was noticed, and even under discontinuous veins of sand that were found bedded in the clay. The number of these drains was gradually reduced, and finally they were only placed under well defined layers of eminently permeable earth having a certain extent and continuity.

Over the entire surface was spread a filtering layer of 2 to 4 inches in thickness, formed of spalls from the dressed stone and those split by frost or of too small size to be used for facing. Gravel, pieces of brick, furnace slag, or any other substance that

would form an eminently permeable earth could be used, but it is very important that the pieces should be perfectly clean and well cleared of all earth that might obstruct the voids and stop the flow of the water.

The revetments were made of dry stone, of a quality easily cut, allowing us to make an excellent piece of work at small cost. They were made 1.5 ft. thick, and for dry stone revetments we think that they should never be less than 1 ft., and it is never necessary to make them more than 1.67 ft. The thickness to be chosen will also depend upon the degree of the slope, the consistency of the clayey mass and the care that can be bestowed upon it. We think it always better to make them of dry stone. If the expense appear to be too great and it is decided to make the revetment of sod or vegetable earth, they must be made much thicker; in order to replace stiffness with weight, the slope must be lighter, and it will be prudent, moreover, to increase the thickness of the filtering layer and make it from 4 to 6 inches in thickness to reduce the chances of obstruction.

At the foot of the paving a masonry ditch is made which gives excellent results. This is shown in fig. 6.

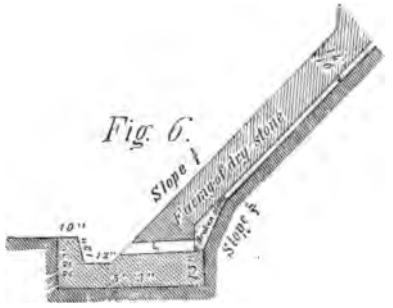


Fig. 6.

It has at the back a base at which the water passing through the filtering layer stops and then runs into the ditch through weep-holes. It is very important to lay the lower part of the masonry mass that forms the bottom of the ditch immediately after the trench is dug, and to completely fill this trench by placing the masonry well up against the earth at the sides.

To carry the water to the weep-holes the part of the base between them must be highest at the centre. Another precaution that it was found well to adopt was to smooth down a thin layer of

mortar on the upper part of the base so as to form a sort of capping to assist the flow. The weep-holes were placed at intervals of 16.50 ft. Special ones were made for the flow of water from the drains, it being brought to the ditch by pipes laid under the paving.

In some parts where the earth was worse, the dimensions of the masonry mass were increased, so as to make its resistance to the enlargement greater, taking care always to set the masonry well up against the side of the trench, and also to preserve the general arrangements made with a view of ensuring the flow of water.

At several points we tried to drain the ground by means of spurs of broken stone, but whenever this method was used we had slips. This result is mainly attributed to the fact that so many divisions assist the enlargement. It is much better to use the material needed by these spurs for adding to the thickness of the paving.

Nowhere has the repressive system, holding up tumbled down earth with retaining walls, been tried. Disintegrated earth has always been removed. As a rule the voids left by this removal have been kept, the fresh earth in rear being drained and revetted. In some unimportant pockets the profile has been re-established by means of a filling of vegetable earth well rammed; but the precaution was taken, and we think it should always be taken, of separating the filling from the unbroken earth by a filtering layer, sufficiently thick to not be obstructed, and having the lower so arranged that the flow of the water may be perfectly sure.

It is only by an attentive study of the ground and the experience of like works constructed in similar cases that the best arrangements for stability and at the same time the most economical can be found; but we think that by judiciously applying the principles just laid down, accidents can always be avoided in the slopes of cuts.

Slopes of Fills.—The same rules and the same methods should be applied to the slopes of fills, if the clayey earth of which they are made have acquired the consistency of the unbroken earth. For fills made in thin horizontal layers, and settled during construction by rolling or ramming, we are convinced that a filtering layer and revetment will always be sufficient. But where the fill is made from the top, after the manner of railroad work, the conditions are entirely changed. There the greatest voids, and consequently the greatest accumulation of water, are found at the bottom.

The complete disintegration of the fragments is possible, so that a division of the mass by seams in which the hydraulic pressure acts is no longer caused, but a true softening, that may involve crushing, takes place. A surface revetment is no longer enough; we must also try to drain the mass. But while doing this we must look out not to interfere with the settling, as it is really important that this should take place as quickly and regularly as possible, so that the penetration of the water shall rapidly become less.

We do not think that the division of the fill by ditches in which dry stone spurs are placed gives the best results. It is impossible, in the first place, to make these spurs before finishing the fill. Hence the system is costly and does not prevent slips while work is going on. If the settlement be not complete when the spurs are built, we delay it. If it be complete, the cohesion of the mass is lessened by dividing it.

General Methods for Solidifying the Slopes of Fills.—The following method, deduced from the considerations set forth on the formation of fills, seems to us bound to give good results:—

The most dangerous action of the water takes place at the foot of the mass; this, then, is the most important point to be drained. Now, we always arrange the base of a fill that we may drain it by means of preliminary works constructed at the surface of the ground on which it is to be made. For this purpose we must make a certain number of shallow drains, of which the inclination must be carefully fixed to ensure the flow of the water to one or both sides of the line. Between these drains the ground must shelve down to those on either side. The drains must be filled with pebbles or gravel to give an easy passage to the water, and on the shelving beds must be put a layer of the same materials so thick that it cannot be obstructed by the earth of the fill. There will thus be formed at the surface of the natural earth an artificial eminently permeable layer that will drain the bottom of the fill. This drainage will be sufficient to prevent, during settlement, slips caused by softening and crushing of the clay; the settlement can then be allowed to go on, and when it is thought to be finished a surface revetment and filtering layer can be applied to the slope, making sure that, at the foot of this revetment, the water can flow freely away from the filtering layer and from the drains made under the fill.

The trial made of this method under one fill cannot be given as

a complete confirmation of its efficacy, but it has given excellent results. This fill was made on clayey earth. A part was already built when considerable slips took place, extending over almost the entire mound. Unloading the earth was stopped and trenches were driven through the foot of the overturned part as far as the unbroken earth. In this earth drains were dug with a steep slope to the outside, and in them was placed dry stone rising slightly above the natural earth. These trenches were then filled in, with the clay of the fill well rammed. In the surface of the ground corresponding to the remainder of the embankment not yet built, were placed other drains filled with broken stone, then the fill was continued with the same clayey earths. After this work was done no movement took place either in the part where the slip had already occurred or in that afterwards built. A flow of water took place in the drains, but after a while it ceased.

In a clay fill that has thoroughly settled, the penetration of the water is less easy than in the earth where a cut has been made, on account of the mound-like shape of the fill. The top surface through which the water penetrates is of small extent, and it is easy, moreover, to regulate the slope so as to ensure its flow.

On the other hand, water flows rapidly over the slopes, if the surface be not worn, without penetrating the mass. Hence there are fewer chances for slips in the slopes of fully settled fills than in the slopes of cuts. The inclination of these slopes is also less steep than that of the slopes of cuts, so that the revetments need be neither so stiff nor so heavy. Hence the use of pavements is generally needless; at most they may be put at the foot where a greater resistance is necessary. Sod or vegetable earth revetments are sufficient; but, as in the slopes of cuts, we think them dangerous to a certain extent, if applied directly to the clayey mass without a filtering layer between. This layer may not be absolutely necessary, if the earth composing the fill be not too bad, but if it be left out, it is then better to limit the thickness of the revetment to what is absolutely necessary to prevent the effects of frost on the clay and to favor vegetation.

IV.—OTHER CONSEQUENCES OF THE MODE OF FORMATION OF EARTHS.

The few new ideas that we have been able to present on the means of protecting slopes in clay are deduced from our observa-

tions on the formation of earths. It follows from these observations that the various particles of which earths are formed may be grouped in fragments of which the consistency approaches that of solid bodies. These fragments are separated by fissures that we call seams. The formation of these seams appears to obey certain laws that vary with the elements entering into composition of the earths. We have pointed out the influence of these seams on permeability, penetrability, circulation of air, development of the roots of plants and the stability of earths. From this last point of view, the main fact that we notice is the preservation of the water entering the seams and the pressure that it exerts when it rises to a certain height. It is to this pressure and to the diminution of the consistency of the earth caused by seams, that the slips caused in the clayey masses must be almost wholly attributed.

This result is not the only one that seems to follow from this observation. Other useful consequences for all questions relating to equilibrium can be deduced. Up to the present time, when these questions have been submitted to calculation, earths have been considered as composed of juxtaposed particles, without considering the cohesion with which they are endowed and the action of the water introduced into the mass. At least, if any attempt were made to consider them, the suppositions made in this respect were wholly insufficient, so that the results deduced therefrom were not confirmed in practice. To prove our assertion, we need only recall the number of disappointments caused by the calculation of the dimensions of retaining walls.

Calculation of Retaining Walls.—In the article before mentioned, M. Collin, discussing Coulomb's hypothesis, which first served as the basis for the calculation of retaining walls, shows that it is applicable only to vegetable earth, to earthy sand, to debris of rocks, and in general to earths having but little and often no cohesion. Nor does he think that we should take as a maximum limit of the pressure exerted on the wall, that of a liquid having a density equal to that of fluid earth. In his opinion the thrust is that of a solid body moving along a curved surface, and it may be much greater than that of a liquid of equal density. The assertion of M. Collin is certainly erroneous under his starting supposition.

If the only active force be the weight of the detached mass, it cannot cause the only possible movement of this mass, that is rotation, without sensibly lowering the centre of gravity. The pressure

exerted by this mass cannot be greater than, nor even equal to that of a liquid. There really exists another force outside of the detached mass; it is the hydrostatic pressure in the seam. In our opinion the problem must be differently stated. We must imagine the mass sustained by the wall as detached by a seam in which the hydrostatic pressure acts, and seek the action exerted on the wall considering the pressure and the other forces such as the weight of the detached mass and friction, both along the seam and on the back of the retaining wall. From the expression thus found will be deduced the shape and position of the separating surface, to which will correspond the maximum action in the wall and the value of this maximum which will serve to determine the dimensions of the wall.

Line of Least Resistance to the Opening of Seams.—Our observations may also allow the solution of other equally interesting problems. Such would be the one consisting of finding, in earth having a given profile, the line of least resistance to the opening of a seam, starting from a given point either at the surface of the slope or behind the crest. Perhaps the solution of this problem would show that in certain cases this line of least resistance is really a cycloid, and thus prove the conclusion deduced by M. Collin from his observations.

Influence on Vegetation.—The fact of the existence of seams, and a more complete knowledge of the laws governing their formation, may still have interest in another order of ideas. Seams certainly play an important part in vegetation, and this importance of the physical condition of earths should not be less than that of their chemical composition. May not the different ways in which seams are formed and act in calcareous and clayey earths explain more closely why certain plants are developed more easily in the one than in the other?

We merely point out these questions, for the solution of which we may profit by all the new observations on the constitution of earths. If the demands of our service do not allow us to study them just now as we should wish to do, we have thought well, however, to give the result of our observations by calling attention to the consequences that may be drawn therefrom.

STEEL IN CONSTRUCTION.

By Albert F. Hill, C. E.

[Results of an experimental inquiry as to the adaptability of steel to purposes of construction. Read April 20, 1880.]

Within the last few years there has been developed in this country a tendency toward steel construction, which to-day is so pronounced as to command the most thoughtful consideration, alike of constructors and manufacturers. The adaptability of steel to purposes of construction is probably no longer questioned, for even the most conservative would find it hard to resist the logic of accomplished facts, as pointed out by numerous successful steel structures, both in this country and abroad. Yet there is still a certain distrust of the material lingering in the minds of many thoughtful men, who believe steel to be endowed, more than other material, with that exasperating quality which might be fitly called "the innate cussedness of inanimate objects." This arises undoubtedly from some of the remarkable and seemingly inexplicable failures which have occurred in finished parts of steel, some of them breaking under loads utterly inadequate to produce rupture, others breaking, in some instances, without any apparent cause at all. I use the expression "seemingly inexplicable" advisedly, for I believe that every such extraordinary failure is susceptible of a rational explanation, and can almost invariably be traced, not to any inherent defect in the material itself, but to wrong treatment of the steel during the process of manufacture into the finished part or article.

Of course the constructor cannot afford to lose sight of the conditions imposed upon him by the mechanical properties of the material he desires to use, and therefore, in order to harmonize his demands with the possibilities of the manufacturer, there is requisite on his part a thorough knowledge, not only of the mere ultimate strength of the material, but also of the best methods for its treatment in the various stages of manufacture.

In the present state of our knowledge and with the late improvements in the manufacture of "open hearth" steel, the two great essentials—variety of grade and certainty of product—are at the command of the steel maker, and therewith all the necessary elements to successfully meet the requirements of the engineer.

The great advantage which the substitution of steel for iron in construction offers, lies in the opportunity which its greater strength and safety afford to reduce dead load. But to carry this reduction of dead load to its full extent, it is necessary not only to take into consideration the strength of the material, but also to adapt the grade of the steel to the work for which the different parts are designed, and to proportion accordingly, due regard of course being paid to the treatment the members must undergo in the course of their manufacture. That is, members which have to undergo a great deal of local heating, ought to be of lower grade than those which, after coming from the rolls, can be finished cold, etc.

In this possibility of adaptation of grade to the work required of the finished part, is to be found not only the beauty and great advantage of steel construction, but perhaps also one of the chief obstacles to its more general introduction thus far; for different grades of steel possess not only different degrees of strength, but are also radically different in their other mechanical qualities and require different methods of treatment in the working; and hence a successful adaptation of grade necessitates a more extended knowledge of the nature of the material than is requisite in iron construction.

Carbon being the element to which, in a greater degree than to any other, the modification of the mechanical properties of steel is due, the most comprehensive, and at the same time the most convenient designation for the different grades of steel is in accordance with the carbon analysis. It therefore becomes at once evident that all records of tests and experiments in steel, to have any practical value and to be of general service to the profession, ought to be accompanied, if not by a full analysis, at least by a statement of

the carbon percentage of the steel under investigation. Another difficulty in the way of obtaining generally available information, is to be found in the fact that so many important experimental inquiries are conducted with prepared specimens, and those even of very small size.

Results on the influence of temperature upon steel obtained by heating knitting needles in naphtha, while undoubtedly very interesting to scientists, will not carry conviction to the minds of men who have to handle the material in large masses. Test results from millimeter specimens prepared in lathe and planer, cannot and ought not to be taken as a true criterion of the mechanical value of a constructive material.

I propose to lay before you this evening the results of some steel tests, made under such conditions as would naturally arise were the material to be used in a structure. These tests were made partly at the Keystone Bridge Company's works at Pittsburgh, partly at the works of Messrs. J. M. & J. B. Cornell, New York City, and partly at the U. S. Arsenal at Watertown, Mass. The steel which has been used in these tests was open hearth steel, made by Messrs. Anderson & Co., of Pittsburgh, and was taken from different runs. The grades range from 0.30 to 0.50 per cent. carbon, and the steel was made into eye bars, plates and riveted plate girders. Tests were also made on the comparative value of drilled, reamed and punched holes, as well as upon the mechanical effects of punching, shearing and annealing.

I ought to state here, that while all the eye bars made of 0.30 per cent. carbon steel were taken from the same run, the 0.30 per cent. carbon plates were taken from another; the same was the case with the 0.50 per cent. carbon eye bars and the 0.50 per cent. carbon plates, etc.

In order to bring as large a field of investigation as we propose to cover this evening within the scope of a fugitive paper, it is necessary, of course, to be as brief as possible. I will therefore simply state the *modus operandi* of the investigation, with its results, and then in the discussion of these results bring out the conclusions to which they seem to lead.

The first series of tests I beg to call your attention to are tensile tests on eye bars. Eighteen eye bars were made and divided into two groups, according to the carbon percentage of the steel, viz.: Nine were of 0.30 per cent. carbon open hearth steel, and nine were

of 0.50 per cent. carbon open hearth steel. Each of these two groups of nine bars was subdivided again into three groups of three each, according to the method of their manufacture, viz.:

1. Three of the 0.30 per cent. carbon and three of the 0.50 per cent. carbon eye bars were made by the Kloman patent process of rolling eye bars, and designated "rolled bars."

2. Three bars from each of the two groups were rolled to the required section of the stem, with sufficient surplus of length to form the heads by hydraulic upsetting, and designated "upset bars."

3. In the last two groups of three from the 0.30 per cent. and 0.50 per cent. carbon steel respectively, the heads were formed by welding pieces and die forging, and are designated "welded bars."

The bars, from steel of equal carbon percentage, had all equal sections of stem, and equal head dimensions and pin-holes. All the bars were annealed before drilling.

As it was important not only to ascertain the relative strength of the 0.30 and 0.50 per cent. C. steel bars, but also to make comparisons as to the effects of the different methods of manufacture upon the strength of the finished bar, there were taken, previous to their being worked into eye bars, from each group of nine bars, five, from the ends of which test pieces, 30 inches long, were cut and broken in the testing machine.

The results obtained from these test pieces are grouped in Table I.

I.—SPECIMEN TESTS OF BAR ENDS, 30 INCHES LONG, DESIGNED FOR EYE BARS.

Mark and Carbon.	Tensile stress per square inch at		Averages.		Stretch per cent.		Reduction of area per cent.	
	Elastic Limit.	Rupture.	Elastic Limit.	Ultimate	Each.	Average.	Each.	Average.
1	55,712	94,760	55,635	95,390	15.1	14.3	30.	28.6
2	56,009	95,380			12.9		26.	
3 0.30 per cent.	55,120	95,830			15.3		31.	
4	55,830	96,020			14.5		27.	
5	55,512	94,970			13.8		29.	
1	65,790	112,340	65,904	112,630	10.8	10.1	19.	19.6
2	66,040	112,470			8.9		16.	
3 6.50 per cent.	66,160	111,980			10.5		22.	
4	65,550	113,320			10.9		21.	
5	65,980	113,040			9.4		20.	

Keeping these results in mind, and comparing them with those obtained from the eye bar tests, as given in the subjoined Table No. II, we are led to the following conclusions, viz.:

II.—EXPERIMENTS MADE ON O. H. STEEL EYE BARS MANUFACTURED BY DIFFERENT PROCESSES.

Mark.	Carbon. Percentage.	Dimensions of Stem.	Dimensions of Head.	Dimensions of Pin-hole.	Mode of Manufacture.	Tensile stress per sq. inch in lbs. at Elastic Limit.	Tensile stress per sq. inch in lbs. at Rupture.	Stretch. Percentage.	Reduction of area. Percentage.	Remarks.
B1...	0.30	3 in. by ⅝ in. by 10 ft.	1¼ in. thick, 7½ in. across eye.	3⅝ in. diameter.	Upset.	54,026	87,400	8.2	44.	Broke 1' 3" from pin-hole.
B2...	0.30					54,113	94,500	9.2	46.	Broke 4' 3¾" from "
B3...	0.30					54,113	89,300	7.0	42.	Broke 1' 8¼" from "
						54,083	90,400	8.1	44.	
F1...	0.30				Rolled.	51,762	92,672	8.2	0.0	Broke in head into 3 pieces
F2...	0.30					54,065	91,570	9.3	29.	Broke 5'2¼" from pin-hole
F3...	0.30					52,518	94,780	11.8	40.	Broke 2' 1¾" from "
						52,781	93,007	9.2	34.5	
A1...	0.30				Welded.	58,473	69,140	2.0	Measurements not taken.	Broke 5¼" from pin-hole.
A2...	0.30					56,059	63,000	2.6		Broke 5⅛" from "
A3...	0.30					55,310	69,400	2.2		Broke 5⅜" from "
						56,614	67,180	2.3		

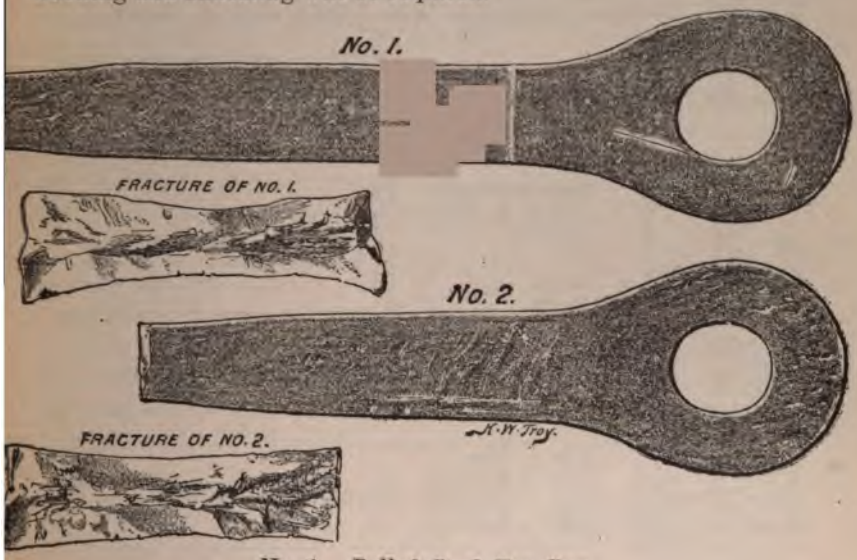
FRACTURES.—In group B1, B2 and B3, fine, silky and wedge-shaped; F2 and F3, same as before; F1 broke in head into three pieces, and showed effect of overheating; fracture coarse and granular. A1, A2 and A3 broke in stem, close to neck; fracture close grained, 50 per cent. garnular, and showing effect of welding heat. Weld in head perfect in all three, but defective at junction of stem and neck on account of welding pieces having been too small.

1. The strength of the specimen exceeds in each case that of the manufactured bar.

2. The uniformity of the results obtained from the tests of the bar ends, shows conclusively that whatever difference in strength there is between these bar ends and the manufactured eye bar, is properly ascribable to the mode of manufacture.

3. The results obtained from the "rolled" and the "upset" eye bars approach nearest to the original bar strength, and give the best results. The difference between the results from these two methods is so trifling, and if anything—in the 0.30 per cent. carbon group—slightly in favor of the upset bar, that it leaves no doubt in my mind that these two processes are equally good.

4. The results from the "welded" bars show that while steel can be perfectly welded, there is a loss of nearly 30 per cent. of ultimate strength as compared with the original bar; moreover, the elastic limit is too near the ultimate strength, and the percentage of elongation too small to give sufficient warning of impending failure. It will therefore be safe to conclude, that welded members in steel construction, while no worse than welded iron ones, are not desirable, and, in fact, ought not to be admitted at all, except where the grade of steel used is very low, and then the greatest caution in working and annealing will be required.



No. 1.—Rolled Steel Eye Bar.
No. 2.—Upset Steel Eye Bar.

The results obtained from the experiments with eye bars from 0.50 per cent. carbon steel, bear out very fully the above conclusions. Another group of nine eye bars, made of 0.40 per cent. carbon open hearth steel is now under preparation for testing, and until this immediate grade is tested, a full comparison is not possible. It will therefore suffice to state here, in a general way, that this group of bars from 0.50 per cent. carbon steel gave somewhat better results in the "rolled" bars than in the "upset" ones, while the loss in the "welded" bars, notwithstanding perfect welds, was so

great as to clearly establish the fact that welding of high grade steel for purposes of construction is out of the question in general practice.

The next series of tests which I beg to submit to your consideration, are plate tests, made upon rolled plates from 0.30 per cent., 0.40 per cent. and 0.50 per cent. carbon "open hearth" steel, respectively.

To obtain primarily a fair average of the strength of the plates as they came from the rolls, and to establish therefrom a coefficient for the different percentages of carbon, three groups of five each, according to carbon percentage, were tested, with the results given in Table III.

III.—EXPERIMENTS MADE ON ROLLED OPEN HEARTH STEEL PLATES.

Mark.	Carbon. Percentage.	Dimensions.	Tensile stress in lbs. per sq. in. in direction of rolling at— Elastic Limit.		Rupture.		Per cent. elongation.—Average.	Remarks.
P 1...	0.30	¾ in. by 12 in. by 6 ft. long, tested as they came from rolls; crop ends sheared; 50 in. between jaws of machine.	43,260	44,380	79,120	78,320	19.3	Fractures fine and silky.
P 2...	0.30		44,820		77,840			
P 3...	0.30		45,110		78,390			
P 4...	0.30		43,990		77,970			
P 5...	0.30		44,720		78,280			
R 1..	0.40		51,620	51,170	81,990	82,480	13.9	Fractures very fine; less reduction of area.
R 2..	0.40		50,980		81,720			
R 3..	0.40		51,260		83,730			
R 4..	0.40		51,100		81,830			
R 5..	0.40		50,890		83,130			
V 1..	0.50		58,950	58,960	85,790	85,980	10.5	Fractures good; slightly granular on edges.
V 2..	0.50		59,200		86,220			
V 3..	0.50		58,540		85,560			
V 4..	0.50		58,880		86,000			
V 5..	0.50		59,330		86,330			

The next step in the investigation was to establish the difference in the strength of the plates in the direction of the rolling and across it. As it was immaterial what the dimensions of the plates or test pieces were, so long as they admitted of a fair comparison of the results, and as it was, at the same time, important to find out what influence the relative proportion of width to thickness of plate might exercise upon the results, plates of different carbon percentage were rolled of different thickness and widths. Table

No. IV shows carbon percentage and dimensions of the rolled plates and the specimens cut therefrom.

TABLE IV.

Carbon.—Per cent.	Dimensions of Rolled Steel Plate.	Dimensions of Specimen therefrom.	Ratio of thickness to width in Test pieces.	Number of Specimens. Cut in Planer. In direction of Rolling.	Planer. Across.	Sheared. In direction of Rolling.	Sheared. Across.	Punched. In direction of Rolling.	Punched. Across.
0.30...	¾ in. thick by 18 in. wide.	¾ x 1½x18 in.	50 per ct	3*	3	3	3	3	3
0.40...	⅜ in. thick by 15 in. wide.	⅜ x 1¼x15 in.	33 per ct.	3	3	3	3	3	3
0.50...	3-16 in. thick by 12 in. wide.	3-16 x 1 x 12 in.	18 per ct	3	3	3	3	3	3

* Each group of three specimens was obtained by taking one piece from each end of the plate and one from the middle.

As it would carry us too far to examine the results of the above 54 tests in detail, the next table, No. V, contains only the average results obtained in the 0.30 per cent., 0.40 per cent. and 0.50 per cent. carbon plates respectively, by cutting out the specimens in the planer, both in the direction of the rolling and across it.

V.—AVERAGE RESISTANCE OF O. H. STEEL PLATES TO TENSILE STRESS IN POUNDS PER SQUARE INCH OF SECTION.

Carbon.—Per cent.	Lengthwise. Elastic Limit.	Lengthwise. Ultimate.	Lengthwise. Elongation. Per cent.	Crosswise. Elastic Limit.	Crosswise. Ultimate.	Crosswise. Elongation. Per cent.
0.30...	49,353	93,339	16	49,510	95,453	18
0.40...	63,227	86,410	14	63,723	87,780	16
0.50...	65,070	83,190	10	65,300	84,995	15

Before entering upon the discussion of the results presented in Table V, it may be proper to state here that both the sheared and

punched specimens showed an equal similarity of strength between lengthwise and crosswise resistance.

It would seem, therefore, that the conclusion that *in steel plates the resistance to tearing is the same, either in the direction of the rolling or across it*, is fully warranted, borne out, as it is here, by 54 tests, made on steel plates of three different percentages of carbon, and of different thickness and widths.

A remarkable feature of the results, as given in Table V, is to be found in the gradual *decrease of ultimate strength* in the three groups, with a corresponding *increase of carbon percentage*. Paradoxical as this may seem, the explanation is not far to seek. By referring to Table III we find no such result, but, on the contrary, the ultimate strength in each group increases with the increase of carbon; but then the plates were of the same thickness and width, or, in other words, the ratio of thickness to width was the same throughout the whole series of tests, and, moreover, the plates were tested just as they came from the rolls. In Table V, on the other hand, we find that not only had the specimens been prepared in the planer, but also—as is stated in the fourth column—the ratio of thickness to width changed in each group and was most favorable to the lowest grade specimens.

To these two circumstances are undoubtedly attributable the remarkable results of Table V; and when we consider further, that this peculiar appearance of greater strength in the lower grades is maintained throughout the whole series of tests on the effects of shearing and punching, as will be subsequently shown, the conclusion seems inevitable that the *ratio of thickness to width is a factor of the highest importance in tensile tests*, and also that when deciding upon the value of a material for construction from specimen tests—unless all the attending circumstances of the investigation are known—the results ought to be taken *cum grano salis*.

To ascertain, now, the effect of shearing and punching upon steel, let us compare the results obtained from specimens of exactly the same size and from the same plates as those mentioned in Table V. As has been previously stated, the difference in the results between lengthwise and crosswise shearing and punching was found so diminutive as to give practically equal results; therefore, to make the comparison a perfectly fair one, the results in Table VI will appear averaged in the following table, just as the results of the sheared and punched plates were averaged also. The results upon the

effects of annealing or tempering after shearing or punching were obtained from precisely similar specimens, and are averaged from the same number of tests in each instance:

VI.—COMPARATIVE RESULTS OF THE EFFECTS OF SHEARING, PUNCHING, ANNEALING AND TEMPERING STEEL PLATE.

Carbon.—Per Cent.	Treatment of Specimen.	Average resistance of O. H. steel plates to tensile stress per square inch of section.				
		Elastic Limit. Lbs.	Difference. Per cent	Ultimate. Lbs.	Difference. Per cent	Elongation. Per cent.
0.30	Cut in planer	49 431	.....	94.396	.....	17.
0.30	Sheared	32 570	— 35	74,980	— 20	10.
0.30	Punched	0.0	— 100	63.410	— 33	0.45
0.30	* Punched and hammered cold	0 0	— 100	87,540	— 0	0.55
0.30	* Punched, hammered and annealed	55,780	+ 12	100,410	+ 6	7.5
0.40	Cut in planer	63,475	.....	87,695	.....	15.
0.40	Sheared	46.900	— 28	75 300	— 14	7.
0.40	Punched	0.0	— 100	68,890	— 20	5.
0.40	Sheared and annealed	59.350	— 7	86,160	— 1	16.
0.40	Punched and tempered	52,780	— 17	103,560	+ 19	7.
0.50	Cut in planer	65,185	.....	84.092	.....	12.5
0.50	Sheared	51,666	— 20	79.900	— 6	5.
0.50	Punched	0.0	— 100	78,400	— 7	4.
0.50	Sheared and tempered	60,375	— 8	87,293	+ 4	17.
0.50	Punched and annealed	57,960	— 10	84 900	0 0	12.

* These two results are not averages, but were obtained from single tests.

A careful comparison of the results in the Table VI shows:

1. That both shearing and punching are injurious, *per se*, to all grades of steel, and cold punching far more so than shearing.

2. That both these operations affect the elastic limit—and this is the most important factor—far more than they do the ultimate strength.

3. That apparently the lower grades of steel are proportionately more injuriously affected than the higher grades. At this point the question naturally arises: How much or what proportion of the greater injury in the lower grades was due, in this case, to the greater thickness of the low grade plates? A series of experiments in one carbon with plates of different thickness from the same run, is now in preparation, and will probably throw some light on this mooted point.

4. That the injurious effects of shearing and punching can be almost entirely counteracted by subsequent annealing or tempering in oil from a low heat.

5. That annealing restores the elastic limit to a greater extent than the ultimate, while tempering as above, on the contrary, largely increases the ultimate strength and ductility, but does not so fully restore the elastic limit.

The next set of tests refers to the relative value of drilled, reamed and punched holes. For this purpose strips of certain and equal widths were cut in the planer from the same set of plates.

VII.—EXPERIMENTS ON O. H. STEEL PLATES WITH DRILLED, PUNCHED AND REAMED, PUNCHED AND ANNEALED, AND COLD PUNCHED HOLES.

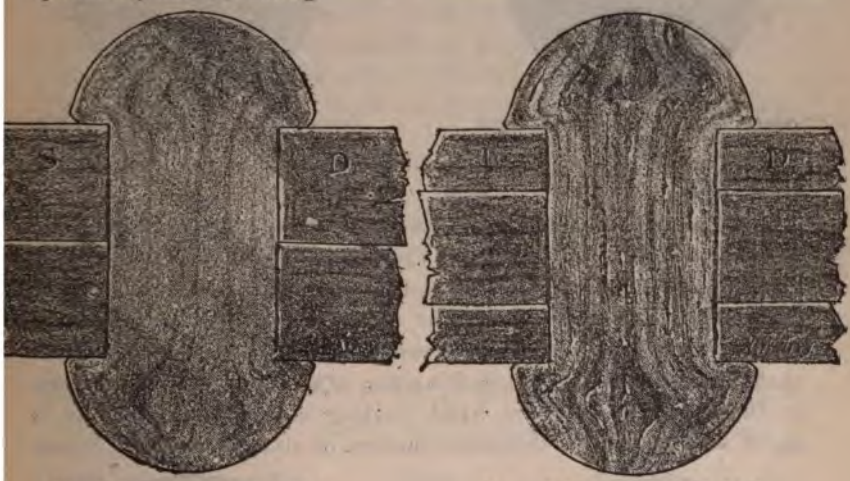
Carbon—Per Cent.	Description of Plate Specimen.	Description of Hole.	Av. ult. tens. str. in lbs. per sq. in. of effective section.	Per cent. Elongation of hole.
0.30...	¾ inch rolled plate, cut in planer on all edges. Strips, 2½ inches wide, 18 inches long.	Drilled, 1 in. in diameter	98,966	22.
0.30...		Punched, 0.935 in. Reamed to 1.1 in. diam	100,700	20.
0.30...		Punched and annealed, 0.935 in. diam	78,970	21.
0.30...		Punched, 0.935 in. diam	66,108	3.3
0.40...	⅜ inch rolled plate, cut as above. Strips, 1¼ inches wide, 15 inches long.	Drilled, 0.6 in. diam	99,747	15.6
0.40...		Punched, 0.5 in. Reamed to 0.62 in. diam	104,253	19.
0.40...		Punched and annealed, 0.62 in. diam	87,910	18.9
0.40...		Punched, 0.62 in. diam	80,550	5.
0.50...	3-16 inch rolled plate, cut as above. Strips, 1 inch wide, 12 inches long.	Drilled, 0.4 in. diam	86,963	29.
0.50...		Punched, 0.4 in. Reamed to 0.5 in. diam	89,043	26.
0.50...		Punched and annealed, 0.45 in. diam	84.951	31.
0.50...		Punched, 0.45 in. diam	82,330	15.

Widths of plates, diameters of holes and tensile resistance, together with ultimate elongations of holes, will be found in Table No. VII. An analysis of the figures shows :

1. That the "reamed" hole is the strongest, and following in the order of strength come the "drilled," the "punched and annealed," and, lastly, the "cold punched" hole. This graduation is well defined in all three groups. That the reamed hole should be stronger than the drilled hole I am unable to account for.

2. That the injurious effect of punching is local, and can be entirely removed by enlarging the hole sufficiently with either drill or reamer. The amount of drilling or reaming required after punching varies with the thickness of the plate and grade of the steel.

3. That although annealing is in a measure beneficial in partially restoring strength and ductility to the punched plate, it will be hardly found available for bridge work, for, if you attempt to anneal before riveting, the holes will not fit; if after riveting, you create internal strains of which no account can be taken, and which may subsequently produce failure. Moreover, with proper machinery, punching and reaming will be found much cheaper than "punching and annealing."



Steel Rivet—Drilled Hole. *Iron Rivet—Drilled Hole.*

In order to establish next the relative value of iron and steel rivets, pieces of steel plate with drilled, reamed and punched holes were machine riveted, both with iron and steel rivets. Sections of plate and rivet were then cut in the planer and afterward treated with acids. The photographs of these sections which are now before you show very plainly—

1. That upsetting affects iron far more injuriously than it does steel, and that, therefore, the iron rivet, irrespective of its lesser resistance to shear, is, *per se*, the weakest.

Steel Rivet—Punched Hole.

Iron Rivet—Punched Hole.

2. That the punched hole cannot be filled by either iron rivet or steel rivet.

3. That the reamed hole is the one most completely filled by both the iron and steel rivet. From these facts, and some tests made upon the resistance of rivet iron to shear, and which gave me invariably smaller results for the same iron, when sheared in steel plates than when sheared in iron plates, it will be safe to conclude that iron rivets should not find a place in steel construction, except in those rare cases where hand riveting is unavoidable, as it is never safe to employ this latter method of riveting on steel rivets.

Steel Rivet—Reamed Hole.

Iron Rivet—Reamed Hole.

A section of an iron plate sheared on the edges and with a punch hole in the centre was cut in the planer and also treated with acid, which brought out the severe distortion the fibres undergo in these operations.

Iron Plate—Punched Hole and Sheared Edges.

In conclusion, permit me to lay before you a transverse test of a riveted steel beam. The composition of the girder was as follows, viz.:

Web, 0.50 C. rolled steel plate, 3-16x12 inches.

Flanges, $2\frac{1}{2}$x$2\frac{1}{2}$x5-16 inch steel angles and 3-16x$5\frac{1}{2}$ inch top and bottom plates.

Rivet holes drilled 9-16ths of an inch diameter.

Rivets, one-half inch diameter ; pitch, $4\frac{1}{2}$ inches.

Effective depth, 12 inches; effective area, 8.51 square inches.

Clear span between supports, 5 feet.

The girder was put into the press without side supports, and the load applied in the centre.

The test results are given below :

VIII.—EXPERIMENT ON 12 INCH RIVETED STEEL GIRDER

Weight, 110 lbs. per yard. Effective Area, 8.51 square inches. Clear Span, 5 ft.

Centre load in lbs.	Deflection in inches.	Increase. Inches.	Remarks.
20,000	.0625	....	
30,000	.0937	.0312	Released. No set.
20,000	.0625	....	
30,000	.0937	.0312	
40,000	.1250	.0323	
50 000	.1875	.0525	Released. No set.
40,000	.1250	....	
50 000	.1563	.0313	
60,000	.2187	.0624	
70,000	.2500	.0313	Released. No set.
60,000	.2187	....	
70,000	.2500	.0313	
75 000	.2813	.0313	
80,000	.2969	.0153	
85,000	.3438	.0469	Released. Set, .0625
90,000	.3750	.0312	
100,000	.6250	.2500	
120,000	.7500	.1250	Released. Set, .2500.
130 000	.9375	.1870	Released. Set, .5000.
130,000	.9375	....	Load remaining. Side deflection begins. Released after 20 min. Set .50.

Comparing the results obtained from this beam with the standard load adopted for rolled iron beams, it will be readily seen that more than double the weight of iron similarly disposed would be required to obtain a like result.

If these hurriedly recited experiments and tests prove anything at all, they prove the wide range of application of which steel is capable in construction, and how imperative the thorough investigation of this subject has become in modern engineering. They are, perhaps, also a wholesome warning to the constructor that it is not wise—in fact, rather otherwise—to depend upon a few specimen tests as a criterion of the value and character of a comparatively new material in construction.

It is beyond all question, moreover, that in adopting steel for purposes of construction, our present methods of dimensioning will have to undergo considerable modification; that our present so-called safety factors, based as they are entirely upon an assumed ultimate strength, become almost meaningless when we have to proportion in steel; and last, but not least, that our mechanics must learn to treat steel as steel and not like iron.

Steel construction is undoubtedly *the* construction of the near future. The conservative element in our profession which opposes it to-day will probably oppose it twenty years hence, just as it took them twenty years to learn to believe that iron was better than wood.

This conservative element is not without its use, neither are sandbags in aërial navigation. To carry out the comparison, let me add that their function and their destiny are alike. They serve very well to steady our flight in the lower levels—to reach a higher altitude they must be thrown overboard.

I ought not to conclude without availing myself of this opportunity to express my obligations to Messrs. J. M. & J. B. Cornell, of New York, and the Keystone Bridge Company and Mr. Kloman, of Pittsburgh, for their many courtesies and valuable assistance in placing men and machinery at my disposal during a most busy season in their works, and also to Mr. James E. Howard, in charge of the United States testing machine at Watertown Arsenal, for his conscientious and faithful work.

THE METRIC SYSTEM.

By Lieut. F. A. Mahan.

[Read May 18, 1880.]

To my great surprise I found, when the notices for the present meeting were sent out, that I was to make a reply to Mr. Kent's paper, read at the March meeting of our Society. Should any of our members have come here expecting to hear a reply, I fear that he will be disappointed, because I have no intention of replying, otherwise than incidentally, to that paper. Some points in it I shall have occasion to touch as I go on. But my object to-night is to try to tell you what that paper does not tell you, viz., what the Metric System is. I suppose that you all have read that paper, and those of you who have not known beforehand what the system is, have found naught to enlighten you. I have read the paper carefully, and the main matter that I find is that there is a certain amount of present bother and present expense that must be incurred in introducing the system, and no consideration is taken of any ultimate advantage or improvement.

Before going further, however, I desire to say that I belong to no society that is trying to force the metric system on the country. I have read none of the controversies between the advocates and opponents of the system, unless it be an occasional stray newspaper article, and what I know about this system I have learned as most practical men (so-called) learn things, by a kind of picking it up without any special study. In my special branch of engineering the only works of any value that I have yet found are in the French language, and in reading them I have learned the system.

Now what is the metric system? It is a system of weights and measures founded on the metre. But what is the metre? It is a measure, nothing more, nothing less. But is it any special measure? It is one ten-millionth part of the length of a quarter meridian measured on the earth's surface, very nearly.

The metric system, like all other systems, is used in measuring lengths, surfaces, volumes, capacities and weights. The unit of length is the *metre;* of surface, the *square metre;* of volume, the *cubic metre;* of capacity, the *litre*, and of weight, the *gramme*. All the units are derived from the metre, as will be shortly explained. The various denominations in the measures of length, capacity and weight have a constant ratio of ten between any one and the next greater. The ratio in measures of surface is 100 or $(10)^2$, and the ratio in measures of volume is 1000 or $(10)^3$. The units to be remembered are the *metre*, the *litre*, and the *gramme*, all short words and easily kept in mind.

Besides the units we wish to express sub-multiples and multiples. This we do by means of seven prefixes, viz.:

milli,	meaning	one-thousandth =	0.001
centi,	"	one-hundredth =	0.01
deci,	"	one-tenth =	0.1
deka,	"	ten =	10.0
hecto,	"	one hundred =	100.0
kilo,	"	one thousand =	1000.0
myria,	"	ten thousand =	10,000.0

These prefixes are easily learned, and a table of prefixes might be formed similar to our dollars and cents, *e. g.:*

10 milli	make	1 centi.
10 centi	"	1 deci.
10 deci	"	1
10	"	1 deka.
10 deka	"	1 hecto.
10 hecto	"	1 kilo.
10 kilo	"	1 myria.

This table is the only one that need be learned in order to know the whole system of metric weights and measures. Its application is the simplest thing possible. If we desire the table of lengths we

simply write *metres* after each word or number in the first column and *metre* after each word or number in the second column, thus :

10 milli – metres make 1 centi – metre.
10 centi – metres " 1 deci – metre.
10 deci – metres " 1 metre.
10 metres " 1 deka – metre.
10 deka – metres " 1 hecto – metre.
10 hecto – metres " 1 kilo – metre.
10 kilo – metres " 1 myria – metre.

To obtain the table of capacities we substitute *litres* and *litre* for *metres* and *metre ;* and to obtain the table of weights we substitute *grammes* and *gramme.*

Mr. Kent says : " The metric system, if it is ever adopted in this country, must be made more simple than it is, for the easy comprehension of the common people." I should like to ask the gentlemen here present whether anything can be much simpler than what I have just given in my table of prefixes; and again, whether anything can be much simpler than to write metres, litres or grammes after the prefixes of the first column, and metre, litre or gramme after the prefixes of the second column. Cannot this table and its use be learned far more readily than our present table of " long measure " alone, not to speak of the tables of avoirdupois weight, troy weight, apothecaries weight, wine measure, beer measure, dry measure, square measure, cubic measure, cloth measure, etc., with all their harmless incongruities of buying by one and selling by another in which people who are not experts in a trade are so easily swindled ?

The whole metric system of weights and measures may be included in the following table :

Parts.	Prefixes.	Length.	Capacity.	Weight.
0.001	milli			
0.01	centi			
0.1	deci			
1.		metre	litre	gramme
10.	deka			
100.	hecto			
1000.	kilo			
10,000.	myria			

In addition to the above there is one weight called the *tonne*, which is equal to 1000 kilogrammes or 1,000,000 grammes. It is used for large weights in the same way as the ton of the present system.

It will be noticed that in the above table the measures of surface or volume do not appear. To obtain them we write the word *square* and *cubic* before the measures of length.

The greatest advantage, to my mind, of the metric system is what, for lack of a better term, I shall call the interconvertibility of its measures of volume, capacity and weight. This will be easily understood by noticing how the units of weight and capacity are found.

We make two vessels, the larger measuring one *decimetre* in length, breadth and depth, the smaller measuring one *centimetre* in length, breadth and depth. The larger is thus a hollow cubic decimetre and is taken as the unit of capacity or the *litre*. The smaller is filled with distilled water at its maximum density. The weight of this cubic centimetre of water is the unit of weight or *gramme*. The relation between the measures of length, capacity and weight are easily remembered by noticing that

metre = *metre*	- - - - -	unit of length.
litre = cubic *decimetre*	- - - - -	" capacity.
gramme = weight of cubic *centimetre* of water		" weight.

From this it is easy to see what the weights of various volumes of water are. The litre of water weighs a kilogramme and the cubic metre weighs a tonne.

Some of the regular terms of the metric system receive special names in special cases. Thus, in measuring wood the cubic metre is sometimes called a *stere*, and in measuring large tracts of land the term *centiare*, *are* and *hectare* are used instead of square metre, square dekametre and square hectometre.

You may remember that Mr. Kent gave us, in his paper, a description of a blast furnace which I shall here repeat, because there are some glaring misuses of the metric system as employed by the French, who, as being the inventors of the system, must be looked to as authority in its use. And let me here say that I was struck, at the time of the reading of the paper, with the peculiar sound of the paragraph, and so soon as it was published in the *American Manufacturer* I sent it to a friend of mine in Paris with

a request that he would submit it to a mining engineer to have the errors in the use of the system corrected. These errors I shall mention as I come to them.

"A blast furnace recently built about 2 myriametres from Pittsburgh, of 20 metres high and 4 metres diameter of the bosh, has recently made the unprecedented quantity of 640 metric tons of pig iron in a week." The distance from Pittsburgh to the furnace would be 20 kilometres had the paragraph been written by a Frenchman. The distance is too short for their use of myriametre.

"The consumption of coke was about 2 cubic metres per ton." The French never measure fuel by volume, it is always by weight. To say that the consumption of fuel was 2 cubic metres per ton is as absurd as to say it was 70 cubic feet per ton.

"The charge of ore was 600 kilogrammes and of limestone 120 kilogrammes per ton of product. The two blowing engines are each 12 decimetres stroke and 22 decimetres diameter, blowing about 6.5 hectosteres of blast per minute, at a pressure of 34 kilogrammes per square decimetre." The use of the hectostere is here incorrect. The term stere is, as I told you before, only used in connection with wood. This quantity would be expressed in French by 6500 cubic metres. Twelve decimetres and 22 decimetres, although correct, are unusual. The French would say 1 metre 20 centimetres and 2 metres 20 centimetres. Pressures of steam, air, etc., are given by the amounts per square centimetre and not per square decimetre. This form of expression, to a Frenchman, would be like speaking of pressures per square foot instead of per square inch, to an American or Englishman.

"The hot blast ovens have a heating surface of 20 ares, which is at the rate of 3 centiares for each stere of blast." The are and its compounds being used only for land measure, it is manifestly incorrect to use them in this connection. This should read as follows: The hot blast ovens have a heating surface of 2000 square metres, which is at the rate of 3 square metres for each cubic metre of blast.

Mr. Kent says in his paper that such news paragraphs as the one he gives "will be quite common a few years after the metric system has been made compulsory." Now I notice that he says that the charge of ore of this furnace was 600 kilogrammes per ton of product. As a ton is 1000 kilogrammes the ore must yield 167 per cent. of iron. As this, according to Mr. Kent, is to be quite the

common thing after the metric system shall have been made compulsory, it is a wonder to me that the blast furnace men do not rush at Congress in a body and demand that the metric system be at once made compulsory, because that seems to be all that is necessary to make the ore yield about 200 per cent. more of iron than it does now.

I shall now consider some of the objections made to its introduction as stated by Mr. Kent. I do not see any advantage in the binary division. These binary divisions can be spoken in the metric system as well as in the common system. A Frenchman is far more apt to say 1 metre and a half than to say 1 metre and 50 centimetres. If he writes a metre and a half he puts it 1 m. 50, just as a railroad engineer would write 1 ft. 50 when he desires to express 1½ feet. But the mischief of the thing is that you can only employ the binary divisions in one denomination. If you are using feet and inches you must use a duodecimal division between the feet and inches, and a binary division in the inches to a certain point. If you use yards and feet, you must have a ternary division between yards and feet, and a binary division for the feet if you choose, but if you add inches to the yards and feet, you have first a ternary division, then a duodecimal division, and lastly a binary division. Now, to show how consistent is this binary division and how great are its advantages, I am informed that when anything smaller than 1-64th of an inch is to be expressed in the iron trade, the decimal system has to come to the rescue. If the binary divisions are something so very advantageous, let us conform our arithmetic thereto and take 16 as a base, according to the system proposed by Mr. Nystrom. Above all things let us be consistent. If our arithmetic be decimal, let us have our weights and measures decimal; if we wish to hold to binary divisions, let us have a binary system of arithmetic. Let us keep but one system and let that system be consistent.

"The incongruities of the present system are harmless and its inconveniences more imaginary than real." This may be true, but people who imagine that a quart is a quart or that a ton is a ton are very apt to be sadly deceived. A person desiring to buy anything by the ton must be careful to specify what kind of a ton he is to receive; he must be sure to say how many pounds are to be in the ton. Or if one desire to have a stone wall built and contract for 100 perches, he will expect to get 2500 cubic feet, unless he have

taken care to carefully find out the value of the perch, but when the wall is finished by the contractor and payment has to be made it is found that the wall contains a trifle over 101 perches. Now I ask any fair-minded man if it be not absurd to have a system of weights and measures in which one unit must be explained by the number of another kind of unit that it is to contain.

The difficulty of familiarizing our people with the new units is something, but it is at the same time comparatively a slight matter. The metric system is taught in the public schools almost all over the country. A knowledge of it is required for admission to our schools of science, and it is adopted as the standard by many scientific bodies. A man who can learn to handle a two-foot rule will soon learn to handle a metre.

The confusion that would ensue in all branches of industry in which gauges, parts of machines, buildings, etc., are made in sizes measured by the foot and inch, is a great argument against the introduction of the system. But this argument seems to go on the supposition that machinery never wears out, new buildings are not to be put up, etc. Take, for example, the Pennsylvania railroad. Suppose that the company should order that all new locomotives built at Altoona after a certain date should be made by the metric system. A planing machine will work as well by the metric system as by the duodecimal-binary system, so will a turning machine, so will a boring machine. To be sure there would then be some locomotives of one system and some of the other. The locomotives of each class are known, and in repairing no confusion would ensue. After a while the old locomotives are worn out, the change is made, and the Pennsylvania Railroad Company will not find itself much poorer. If the United States should order that after a certain time all its business should be transacted according to the metric system, I do not think that any iron dealer would object to bidding on a contract for 1500 or 2000 tons of iron because the drawings were made by the metric system. If the civil engineers and architects through the country would but use the metric system only, make all their drawings and specifications according to it, the manufacturers would have to follow. If a new building is to be put up the metric system could be just as well used as the other.

The argument amounts to very little in the case of land. Measurements of land are not made to less than $\frac{1}{100}$ of a foot. A milli-

metre is $\frac{1}{3\,1\,0}$ of a foot, consequently we should be able to measure closer with the metric system than by feet and hundredths. When a tract of land is transferred, let the first record after the adoption of the metric system be in both forms and at any subsequent transfer let it be according to the metric system alone. Any man with brains enough to make a survey could make the transfer from one system of unit to the other.

The expense of changing scales would be something, but not so great as people ordinarily are led to believe by the opponents of the metric system. For example, a carpenter has to work from a drawing made by the metric system; all he has to get is a new measure. The pocket metre costs about 25 cents. To get it would require him to give up five glasses of beer or a couple of drinks of whiskey, very bad for the brewers and distillers. The same will apply to the yardstick. The cost of changing weighing scales would be greater, but even here all that is needed is a new beam, new weights and a new poise. The cost of this change for the largest size of track scales is about $50. The cost of changing the scales for the Post Office Department we are told is estimated at $125,000, which amounts to a tax of 1.6 cents for each grown man in the United States. This will not ruin the country just yet.

"Who can calculate the expense and inconvenience which would ensue to every engineer and every mechanic if the division of the English foot into hundredths and thousandths were made compulsory, and its division into inches illegal?" I cannot speak very much for mechanics, but for engineers I think I am safe in saying that such a change would be hailed by them with delight. Why did engineers abandon the old 66 feet chain with its links of $7\frac{92}{100}$ inches in length and substitute therefor the chain of 100 feet? Why do they use so much their tape lines graduated to feet and tenths? Why are their leveling rods graduated to feet, tenths, hundredths and thousandths? Why also are some engineers in their transits abandoning the quadrant of 90 degrees and substituting the one of 100 degrees? All for facilitating and expediting work. Gauges that are in use become in time worn out and have to be replaced. The yardstick can well be replaced by the metre, which is quite as convenient to use and to handle as the yardstick, General Meigs to the contrary notwithstanding. The two-foot rules would have to be changed, but whether there are millions of them in use to-day is, I think, open to question. The population of the

United States is about forty millions. Assuming that one-fifth of this number are able-bodied men, we have eight millions. Will any one say that one-eighth of all these are using two-foot rules? Consider the vast army of common laborers, the knights of the shovel and wheelbarrow, what does it matter to them what scale is used? Or take the great part of the men engaged in blast furnaces, rolling mills, etc., how many need a two-foot rule? So far as this rule is concerned, I think that we should have hard work to find *one* million of them in use. I doubt very much whether one person in eight uses the two-foot rule in any shape or form whatever. I can speak from my own experience that no such number as that among the people whom I come in contact with use anything of the kind. Think of the bankers, merchants, lawyers, physicians, apothecaries, grocers, clerks, draymen, not to speak of many other kinds of men too numerous to mention, who probably never see a two-foot rule from the beginning to the end of the year. I will grant, however, that there are *one* million of these rules in use. To replace them with metre rules would cost $250,000, which would impose a tax of $3\frac{1}{8}$ cents on every man in the United States. The changes required in any engineer's pocket-book or in any book of reference upon mechanical or engineering subjects is not a herculean task to effect. I have carefully gone through "Trautwine's Engineer's Pocket-book," and so far as I can see it will be no insuperable task to make the changes required therein. Were the metric system adopted I venture to say that new editions of all works of any value on these subjects would appear before the time set for changing from one system to the other. Judging by my own experience, draughtsmen would be only too glad to be rid of the many scales that they now have, to use and adopt the double decimetre divided to millimetres and halves. Rolls wear out and have to be replaced or redressed. When either of these operations has to be done, let the repairs or new rolls be made according to the metric system. The time spent in learning the metric system would not require a whole generation. A person after using the metre a little while knows it, and can guess in it as well as the duodecimal-binary system. How many of the gentlemen here assembled this evening can tell me the dimensions of this room? Some will guess one size, others another, and so on, and probably not three persons in the room hit it exactly. Guessing can be as well done in one system as the other.

Mr. Kent objects to the number of terms in the metric system, but this objection is hardly tenable. As I showed a little while since, the whole system has three units and seven prefixes, with three alternate names, the stere, the are and the tonne. Two of these, the stere and the are, are for special use, consequently the general tables have but 11 terms to learn. These terms are easily learned, have a constant ratio, and adapt themselves easily to all sorts of calculations. We retain all the terms and have a greater variety of units to choose from for special purposes.

Mr. Kent stands on the same ground as the South did in 1861. He, like them, says: "All we ask is to let us alone." So far as I can see, the manufacturers of iron are the strongest opponents of the metric system. To me they seem to occupy very much the position of the large coal dealers with regard to the improvement of the Ohio river. The radical improvement of the Ohio is opposed because it does away with corners in coal and it thus affects their pockets. Iron factors oppose the metric system because it will cost them a little something to make the change. This would be a good ground of complaint if the iron makers had to stand the cost. Unfortunately for their argument the cost does not come on them, because every cent that this change would cause them they would charge against the consumer.

I suppose that most of you are aware that the Waltham Watch Company has used the metric system of measures for eight years. I wrote to them on the subject and they reply that "the advantages of its general adoption are so palpable that it would be useless to state them, as anybody at all acquainted with the subject would know." Now let us look at some of the harmless incongruities and imaginary inconveniences of the present system. In ordinary long measure are the barleycorn, inch, foot, yard, rod, chain, furlong, mile and league. There are also four other measures not given in the table, the palm, hand, span and fathom. Here then we have thirteen names, not to speak of the fractions of inches. What ratio do we find between the terms of this table? It is 3, 12, 3, 5½, 4, 10, 8, 3, a series wholly arbitrary and offering all desirable difficulty in its use. In how much is this superior to the constant ratio 10 of the metric system?

In square measure we have the exceedingly convenient ratio of 144, 9, 30¼, 40, 4, 640. A little vagary of our land measure is that we use a gauge in measuring land, a unit that is not a square. I

have worked at the acre in two or three different ways. I have extracted the square root to the seventh decimal, but I cannot find the side of the equivalent square. How much better the hectare with its side of exactly 100 metres!

In cubic measure we have 1728 and 27 as the terms of our ratio instead of 1000, the ratio of the metric system.

In measures of capacity we have three systems, beer, dry and wine measure. The beer quart is larger than the dry quart, while the wine quart is smaller. If you go to market to buy a quart of berries do you get the contents of a quart? I think not, unless Pittsburgh dealers are more honest than those of other places. Things of that sort are sold by the smallest measure. Among the measures of capacity we have the gill, pint, quart, gallon, barrel (who can tell how many of these there are), hogshead, pipe, tun, tierce, peck, bushel, chaldron. In wine measure we have the ratio 4, 2, 4, $31\frac{1}{2}$, 2, 2, 2. In dry measure we have 2, 8, 4, 36. Beer measure I have forgotten and I cannot find it in any book that I have at hand. Who will presume to name all the different sizes of barrels, casks, etc., in the country? Who will tell all the bushels? Harmless incongruities, imaginary inconveniences these, that prevent a man from receiving just measure unless he is up to all the tricks of every trade! The metric system proposes to do away with all this and to establish one uniform system.

Let us take a look now at the measures of weight. We have the grain, dram, ounce, pound, quarter, hundredweight, ton, stone, quintal, pennyweight and scruple. In avoirdupois weight we have the series 27.34375, 16, 16, $\left\{\begin{smallmatrix}2\\2\end{smallmatrix}\right.\left.\begin{smallmatrix}5\\3\end{smallmatrix}\right\}$ 4, 20. In troy weight we have 24, 20, 12, and in apothecaries weight we have 20, 3, 8, 12. These systems of weight present some strange anomalies. The avoirdupois pound is much greater than the troy pound, but the avoirdupois ounce is less than the troy ounce. The avoirdupois pound is nearly one-fourth greater than the apothecary pound, while the apothecary dram is nearly twice as large as the avoirdupois dram.

To sum up, we have in the metric system three units and seven prefixes. In addition to these we have for measuring wood the stere, for measuring land the are, and the tonne for large weights. In the common system we have—

MEASURES OF

Length.	Surface.	Volume.	Capacity.	Weight.
Barleycorn	Rood	Cord	Gill	Grain
Inch	Acre	Perch	Pint	Scruple
Foot	.....	.....	Quart	Pennyweight
Yard	.....	.....	Gallon	Dram
Rod	.....	.....	Peck	Ounce
Chain	.....	.....	Bushel	Pound
Furlong	.....	.....	Barrel	Stone
Mile	.....	.....	Hogshead	Quarter
League	.....	.....	Tierce	Cwt
Palm	.....	.....	Puncheon	Quintal
Hand	.....	.....	Pipe	Ton
Span	.....	.....	Tun	.....
Fathom	.....	.....	Chaldron	.....
				.....
13	2	2	13	11

Here we have 41 different terms, the names and ratios being wholly arbitrary. To keep them in mind is simply a feat of memory. No principle pervades the system, and it seems to me that if chance ever had a hand in anything in this world, it was in the construction of the common system of weights and measures How much better, then, to have a system where

> "All would arrange itself to perfect law—
> No breaches, no exceptions, all pure law—"

and this the metric system enables us to do.

Now, to show another of the "harmless incongruities and imaginary inconveniences" of our system, let us take the case of a boy going to school. He begins the study of arithmetic and learns that 10 units make 1 ten; 10 tens make a hundred; 10 hundreds a thousand, and so on. He learns addition, subtraction, multiplication and division. Many a weary hour he spends trying to get the mysteries of abstract arithmetic into his brain. Finally he succeeds, and is sufficiently far advanced to learn the application of arithmetic to the affairs of life. The first thing he finds is that his abstract arithmetic does not amount to much. It does very well so long as he confines himself to one sort of unit, but the moment that he tries to use more than one sort then his ratio of ten is of no account. He finds all sorts of things, and in order to learn them

he has almost to forget what he learned before. Then, too, look at the time to be spent with vulgar fractions, and see how much of the boy's time is literally wasted.

Compare all this with the metric system and its constant ratio of ten. See the saving of time and trouble in not having to learn a mass of tables that will soon be forgotten. Vulgar fractions may also be abandoned, because they are not needed in the metric system where everything is decimal.

"Time is money" just as much in making calculations as in anything else. How much time would be saved if our systems of weights and measures were decimal instead of anything and everything as we have now! Just look at the difficulty of finding the volume of any body when its dimensions are expressed in feet and in these much beloved binary divisions of the inch. Take, for example, a body 3 feet $2\frac{3}{4}$ inches long, 2 feet $9\frac{11}{16}$ inches wide and 2 feet $5\frac{3}{32}$ inches thick, and find its volume in cubic feet and inches without using decimals. The three dimensions must be reduced to inches and fractions, thus:

3 feet $2\frac{3}{4}$ inches $=\frac{155}{4}$ inch.
2 feet $9\frac{11}{16}$ inches $=\frac{539}{16}$ inch.
2 feet $5\frac{3}{32}$ inches $=\frac{931}{32}$ inch.

Now multiply the length, breadth and thickness together, and we have

$\frac{155}{4}\times\frac{539}{16}\times\frac{931}{32}=\frac{7793535295}{2048}=38054\frac{803}{2048}$ cubic inches=22 cubic feet $38\frac{803}{2048}$ cubic inches.

Convert these dimensions into their corresponding values in the metric system and we have

3 feet $3\frac{1}{8}$ inches=0.984 m.
2 feet $9\frac{11}{16}$ inches=0.866 m.
2 feet $5\frac{3}{32}$ inches=0.739 m.

0.984 m.$\times$0.866 m.$\times$0.739 m. $=$ 0.622462756 c. m. or 622462756 cubic millimetres, a quantity that can be readily laid out and measured.

Suppose, further, that we have a trough of the above dimensions and we desire to know how many quarts of water it contains. By our binary system we can make nothing of the volume $38054\frac{803}{2048}$ cubic inches, but if we take the metric system we have at once 622.462756 l., and it weighs 622462.756 g.

Examples can be multiplied without limit to show the advantages of the metric system in all matters of calculation.

The greatest advantage of the metric system is what I have called, for want of a better term, the interconvertibility of the measures of volume, capacity and weight. This is seen in the above example where the volume and weight of the water and the capacity of the trough are all expressed by exactly the same digits, the differences being merely in the place of the decimal point. We know at once the weight of any body so soon as its volume and specific gravity are given. We do not know it "about," but we know it exactly. Everything is fixed accurately.

In the discussion at the March meeting I asked the question, "Who can tell me what volume of water weighs a pound?" The only reply I received was from Mr. Kent, who told me that a cubic foot of water weighs a thousand ounces. I do not know whence he obtains his authority, because I have consulted a great many works, and taking them all I can only find 998.066 oz. as the weight of a cubic foot of water. This, to be sure, is nearly 1000 oz., differing from it by a little less than two-tenths of one per cent. This degree of approximation will not do for engineering. Something more is needed now-a-days by engineers. They are constantly seeking better methods of work, better methods of testing, better methods of proof, and why not better methods of calculating?

Some people object to the metre because it is not exactly one ten-millionth part of the length of a quadrant of the meridian. I do not see what that has to do with it. The government says that this bar is the unit of length, that a hollow cubical vessel measuring one-tenth of the unit in length, breadth and depth, is the unit of capacity, that the amount of water at its maximum density required to fill a hollow cubical vessel having one one-thousandth of the capacity of the unit of capacity, shall be the unit of weight. This would give a system exactly similar in all respects to the metric, provided that in addition to the above the system be made decimal. But why start on any other when we already have a good one at hand?

Some people object to the system on account of the Greek and Latin names. If this be a valid objection let us be consistent and object to all the Greek and Latin names in the language. Let us do away with all art, all science, all manufacturing, in fact we should do away with the language itself. Let us have no philosophy, no nature, no astronomy, no physics, no chemistry, no geodesy, no anything in which learning is needed.

Some, who call themselves the conservatives, we must leave behind. No man, and no set of men, can stay the advance of improvement. Labor-saving, time-saving, are the order of the day. We cannot adopt, in these busy days, the old conservative idea that the foot and inch having been good enough for our grandfathers and our fathers, must therefore be good enough for us. This will not do. "Time is money," and we cannot afford to waste money on a matter that is fast falling behind the times. Mr. Hill at our last meeting told us that the conservatives are like the ballast of the balloon, to be thrown overboard when we wish to rise.

*"The argument for conservatism is so constantly overthrown that its tenacity is surprising. The progress of civilization is over conservatism, and that progress is constant. Conservatism plants itself upon the established order. That has been tested; the new is untried; and while the old is not wholly satisfactory, who knows that the new will not be infinitely worse? Leave well enough alone, and don't lose the half loaf you have in trying to snatch a whole one, is the exhortation of conservatism. This argument, indeed, in all its forms, is forever disproved.

"The infinite series of discomfitures of its argument is rejected by conservatism as wholly inconclusive and inapplicable, and each new inventor, or projector, or reformer, must, as it were, construct a new alphabet. It would be instructive to cite, if it were possible to fill a library of books with the recital, the illustrations of the dull pertinacity of the conservative argument. It was the perception of it which made John Stuart Mill assert that while all conservatives are not stupid, all stupid people are conservative. But while the fat-witted spirit of dullness is essentially conservative, conservatism has not, as it incessantly claims, all precedent on its side. Antiquity and precedent are all against it. History is the story of the violation of precedents and the disturbance of traditions. Conservatism finds no place to lay its head, because the story of the race is that of endless movement. If the world had been content to let well enough alone, the world would have stood still. It is the human impulse not to be content with well enough, but to require the best, and hence mere conservatism or obstruction is constantly worsted."

So it is with the foot and inch. Conservatism says, "hold on to them;" progress says, "cast them aside." They have done good

*Editor's Easy Chair in *Harper's Monthly* for April, 1880.

work in their day, but their day is past. The demand is now for simplicity, facility and clearness. The schools of science all through the land are teaching the metric system, many of them having adopted it exclusively. The graduates of these schools will be the directors of the future, and they, knowing its advantages, will bring it to the front. Engineers will demand it, and manufacturers must yield to it or be left behind in the race. Those who have used the system enough to understand it thoroughly, who have a knowledge of it gained from every day use, and who have seen its convenience in every direction, are in its favor. The opposition is mainly made up of those who, in the words of a prominent member of our Society, "don't know and don't want to know anything about it."

> "'Tis hard to root up all one's faith at once;
> All the old feelings, all the happy dreams,
> All the sweet customs, the long growth of years.
> The very superstitions of our youth
> Have fragrance in them."

But faith, feelings, dreams, customs, aye! and superstitions too, must yield to a force far stronger than we; a force conquering, indomitable, insuperable; a force that conservatism the most pronounced has striven in vain to resist; a force that drives us onward in spite of ourselves; a force that up to the present time no one has been able to oppose, and that force we call PROGRESS.

THE DANKS PUDDLING FURNACE.

By John I. Williams.

[Read Sept. 14, 1880.]

In our day iron is one of the great factors, and anything relating to its manufacture, condition or use, is eagerly seized upon and at once investigated, and in the very general interest taken there seems to be no subject so largely studied as that connected therewith.

At no period of the world's history has there been such active energy and increasing zeal displayed in the development of iron, and especially steel, as in the past twenty years, and I hazard nothing in saying, that at no period has there been such wonderful developments in these materials.

In the rapid progress of steel, especially of Bessemer on the one hand and Siemens-Martin or open hearth on the other, iron has for the time been overshadowed. But iron has its uses yet, and I doubt not will continue to have in the progressive ages yet to come, where both branches will find ample field for all the energies which may be engaged in their production.

In the history of iron we find what might be called three periods, or points of progress:

1. The primitive period, where iron was made in the crude and limited way, by skins sewed together to produce blast, and ores melted in open fires.

2. The advance step by means of the Catalonian process, and of more advanced method of blast and fires.

3. The introduction of the puddling furnaces, including such machinery as necessarily grew out of the rapid progress made, and the increased production of this special period—continued for many years—and many minds doubtless were deeply interested in the development and progress of this period.

But to our day has been left the crowning glory of almost perfect development. Who of middle age is there, at all interested in iron, cannot remember what a great mystery there was in a blast furnace, when the making of good metal was merely a matter of chance, apparently, and a few men (and very few) were looked upon as furnace doctors, and were sent for, here and there, to help sick furnaces?

But how changed now. Science has stepped in, and the analytical chemist tells you the causes and the remedies for many of the ills to which blast furnaces are subject, and by their use, or disuse, have rendered the production of the various qualities of metal a mere matter of combination.

But while many have been engaged in the study of iron, and have been deeply interested in the progress made, both in quality and production, there were other questions coming up which were forcing themselves on the attention of those who were more directly in contact with the production and the means employed, and among the things calling for consideration was the lightening of labor, and increased production, as well as the difficulty which was everywhere making itself manifest in iron districts by the combinations of labor against capital, and the bitterness engendered in the strife growing out of strikes.

It was at this period that the Danks furnace had its birth. Samuel A. Danks, a man of large experience, good mechanical ability, and an earnest, active thinker, developed its principal features, and deserves better of the iron world than he has fared. To him belongs the credit of its conception and introduction—as far as I can learn. He first began his investigations while at Troy, N. Y., continued them at Mount Savage, Maryland, and put them into shape and practice at Cincinnati, O. My own mind had been looking over the same field for some time, and on inquiry at the Patent Office found myself anticipated by Mr. Danks. Believing that many advantages were combined in the furnaces, I called the attention of Messrs. Graff, Bennett & Co. to the matter, as I was then engaged with them at their works at Millvale, who, after

investigation and correspondence with Mr. Danks and partners, finally concluded to erect a plant.

The construction and operating being delegated to me, it was commenced at once. At this time there was no subject which seemed, at least, to agitate the public mind so much as did the question of the Danks furnaces. Mr. Danks had made a square fight with labor, and had dispensed with all puddlers—carried on successfully, to all appearances, a large business independent of puddlers or boilers—and had established such a reputation for quality and quantity of production as to attract wide attention, not only in this country but in Europe also. A commission was appointed by the iron interests of England, who brought metal and material over from there, for a thorough and exhaustive trial; and many of you doubtless remember the very satisfactory report made by that English commission, and the excited condition into which the iron manufacturers of that country were thrown. Mr. Danks, by invitation, went to England; large amounts of money were spent in the erection of plants; new companies were organized, and a complete revolution in iron seemed very imminent. On the Continent, also, much interest was felt, and many experiments were made. In the meantime we had got to work, and I cannot do better than to almost bodily enclose in this my article in the *Metallurgical Review*, No. 1, Vol. 1, of September, 1877, published by David Williams in New York.

"'What of the Danks furnace?' has become, to me, as familiar as a household word from its constant repetition, not only by those interested in its working, but by the merely curious. I have taken this way to reply to the question, and propose, in my plain way, to say what I think of the Danks furnace and state the results of my observation and practice with it.

In the first place, it is a simple act of justice to say that Mr. Samuel A. Danks deserves, as few men do, to be honored and rewarded while living, for the advanced step taken in this iron age in the development of a puddling furnace which, in a modified form, is destined to supplant the hand puddling furnace and lighten the labor of the most exhausting occupation known to civilization. To him clearly belongs the credit of the conception and development to such a degree as to awaken the attention and secure the investment of capital in a furnace so correct in general principles as to cause men to have unbounded faith in its ultimate success.

It is true, Mr. Danks has made many errors, both in theory and practice, but the tenacity and endurance shown by him in the defense of his views are worthy of the highest admiration, and in the coming day of the complete triumph of machine puddling it will be counted to him a virtue.

'But what do you think of the furnace?' some one asks again. As a worker of metals, I think it has no equal; as a melter, it is inferior to many; as to endurance, it *was* the shortest lived of any, and as to convenience of repairs, it *was* one of the most difficult. As to quality of iron produced, it has reached a plane so far above all others that it stands pre-eminent. As to production or output, it is double now, with every reason to believe it can be quadrupled. But after this enumeration of its excellencies and imperfections, the question naturally arises: Are not its good qualities more than balanced by its defects?

To this I reply, that it is an innovation on established methods, and is as susceptible of improvement as nearly all new things are—more so, perhaps. Two points of superiority in the above enumeration should be carefully noted:

1. As a worker of metals it has no equal.

2. As to output it excels all others. All other points enumerated are mechanical and can be modified.

Some of the defects existing in the original furnace have already been corrected, and others will be soon. It was for the two reasons above named that I consented to give the furnace a trial, and, as soon as possible after the commencement of operations, to begin the task of remedying defects as they became apparent, holding fast to the idea of quality.

As the superintendent of the Millvale mill of Graff, Bennett & Co., I received from Mr. Danks drawings of what he claimed to be his most perfect furnace, and furnaces were erected in strict accordance with these plans.

My first difficulty was the want of experts to run them.

This need occasion no surprise. I say experts, and, I would add, if any one takes hold of the Danks furnace with the idea that unskilled labor is competent to operate it, I am certain both furnaces and men will not be 'damned with faint praise,' but right heartily.

In the well defined antagonism of labor and labor organizations to my efforts, I found a watchful and unceasing enemy. I had to make haste slowly.

It had been assumed not only that the furnace had been, but would continue to be, a failure, and that the longer we 'fooled' with it the worse it would be for the idea of machine puddling.

It was this fact, I am well convinced, that modified somewhat the hostility of labor organizations against us, and, perhaps, enabled us to overcome such antagonism as offered itself.

Beside these difficulties with labor, we found, upon trial, the latest type and model furnace, as set forth in the drawings of Mr. Danks, so difficult of operation that many times I wished I had never seen it.

Presuming that those who will be interested in this paper are acquainted with the Danks furnace, or, at least, know enough of the general features of its construction to render unnecessary a description of it, I shall only give such details of construction as are necessary to show the improvements that have been made and the reason for the same, as well as the results attending such improvements.

The first trouble experienced was with an insufficient fire surface. This was found totally inadequate to the work demanded of it, the heat secured not being sufficient to work the iron thoroughly and rapidly.

The fire surface was enlarged nearly fifty per cent. over that called for by Mr. Danks' drawings.

Next, I found that a special brick was wanted in the arch over the bridge and in the movable neck, which, from its peculiar position, it was almost impossible to retain in place, and very many trials were required to secure the necessary quality. To add to the difficulty, Mr. Danks, for some reason, used three different shapes of brick. These I have reduced to one.

Again, I found his stationary as well as movable neck a covered inclosure, making it necessary to key from below the arch or from the end.

As a result of this method, it was almost impossible to sustain the arch, which was constantly caving in from lack of proper keying.

This defect I remedied by cutting an opening in the movable neck and connections on the top side of the arch, so as to key the arch from above and thus get a firm condition of masonry. Another serious evil was the arrangement of the water collars on the fire bridge end of the furnace. This collar, in the Danks plan, was secured by four bolts equally spaced, or nearly so. The severe

strains from the large expansion and contraction caused frequent breakage of this collar, and its removal for repairs required the removal of at least one-third of the most costly part of the masonry.

This I have obviated by cutting the collar into two pieces and casting a flange on the lower section, and grooves in the bridge plate to receive it, and having the bolt holes on the top side so arranged that they come above the brick work.

By this arrangement the collar can be readily removed and replaced by taking out one bolt from each section, lifting it out, letting another section supply its place into the groove below, and bolting.

To more perfectly remedy these evils, in the latest improvements I arrange the furnace and working chamber in such relative positions that a curved, crooked or angular removable flue, or flue section, can be made to connect the fire chamber with the mouth of the working chamber. By suitable sliding rails this flue section is mounted on ways, or by other equivalent devices of like function, made removable for convenience in making repairs, and also adjustable. I also found the front collar on the movable neck liable to rupture, the water pipe (wrought iron) which was placed inside the cast section often breaking from the expansion of the metal.

This I have partially overcome by cutting in the mould the upper part of the ring just at the point where the water pipes approach each other, and between them. By this simple device the enclosed wrought iron pipe is relieved, as well as the cast collar, it being freed at the ends and thus allowing expansion and contraction. A still more serious trouble was experienced as the result of the peculiar shape of the revolving body.

In Mr. Danks' plan we found the ends of the body so nearly at right angle to the axis of the barrel, that by the expansion of the 'fix' or fettling the end rings—which at best had very tempora[illegible] attachments—were constantly giving way, either at the rivets [illegible] rivet holes, or completely breaking away. If a rivet gave way t[illegible] ring very soon broke at that point. If the ring broke at the riv[illegible] hole then out it went, and when once out nothing short of [illegible] removal could remedy the difficulty, for as the furnace revolved let out the metal or cinder, or both, at every turn, on account of t[illegible] uneven surface rendering it impossible to make a close joint wi[illegible] the friction ring. Every day the furnace was run after the ri[illegible]

was in this condition made it worse from the continual expansion of the 'fix'* against the weak point. Both ends being alike, as a consequence the difficulty increased. This I have practically overcome by making the end next the movable neck at such an angle to the axis of the body that the 'fix,' in expanding, slides up the surface of the end ring, and by this means relieves them of the enormous strains to which they were heretofore subjected.

I have also added a right angle flange as well as a parallel one, whereby I add very materially to the resisting strength of the rings.

In doing this I arrange for a series of wrought iron rings, which not only add to the strength but also serve as a guide for water which is thrown upon these rings, thereby cooling parts of the furnace which are of great importance, especially that portion next the water collar on the movable neck.

In the old arrangement, on account of the collar being so nearly vertical to the body, any water distributed on it found its way down into the working chamber, especially if there were any unevenness of surface from broken rings or rivets.

This injured the quality of the iron and often made it impossible to work the furnace. In my arrangement of wrought collar and extended end ring, water can be used with impunity and the fixing maintained up to the very end of the collar.

In fact it is at nearly all times, in my new furnace, from one to one and a half inches thick at the points mentioned, while in the old arrangement, for want of this condition, the iron would adhere to the ring, being often broken in its removal.

As a matter of course, by relieving the outward end from the strain of expansion the back end was also relieved, and being sustained by the fire chamber (a steady resistance), that portion gives but little trouble.

Coming now to the power or driving part, I have no doubt many of the mechanical visitors to the Millvale works have inwardly laughed at the engines used to revolve the original five furnaces put up from plans furnished by Mr. Danks, the engines being trunk engines, (reversing by cams and links.)

Presuming that Mr. Danks' experience was better than my opinion, these engines were constructed as the best adapted to the working of the furnace, and for a very short time did reasonably well. Soon, however, the lower wrists in the trunks got worn, the

* This word is always used as a synonym for fettling.

brasses got loose in them, and then came the thumping and jerking of the pitman. As a consequence nuts shook loose, keys came jumping out, the heat from the trunk extended along the pitman, oil ran like water, and brasses heated up and commenced to cut. The reversing cams, under the heavy surge of the engines from loose joints, would suddenly reverse the engines or send the valves out of place, and cause a dead halt in the rotation of the furnace.

So we went, until my most intimate friends said, 'don't bother yourself any longer; give the cursed things up;' and there were times when it seemed as though I should have to do it. But I had said to our firm, the principle is right, and they had taken hold of the furnace in the full faith that I knew what I said, trusting their large investment in the plant in the belief that I could carry them through. It resolved itself, in my mind, into a choice of three alternatives—great loss to the firm, loss of character to myself, or a victory through much tribulation.

As to which has been attained, I leave others than myself to say.

I may mention at this point, that before this reaches the reader all of the original engines will have been removed, and others of improved character and make, which have given very great satisfaction, set to work in their places, being more positive in their action, less expensive in repairs, more readily handled, approachable at all points for examination and repairs, and more powerful in their execution. One pair has now been running for over three years, and up to the present time has not been overhauled or repaired. Others since built, and running nearly two years, have had nothing more than keys driven, packing set up, bolts tightened, etc.

Passing now to the actual working of the furnace, our operations began with the use of charges of eight hundred pounds of metal and six heats for a day's work. This, by reason of the difficulty of keeping the furnace in working order, as already explained, coupled with the fact that I did not deem it safe to push the workmen, owing to outside influences, was reduced to five heats per shift, and the charge increased to nine hundred pounds and continued at this for some time, until, at the time of the running down of the scale of prices for hand puddling, or boiling, (as no puddling is done in Pittsburgh,) I increased the output to six heats per shift, and deducted from the rates paid in proportion for any deficiency in

heats. Just here I may say, that our prices for labor are based on the highest income of a three months' average of four of our best hand puddlers, with a tonnage added.

The method and labor of working a nine hundred pound charge are as follows: The metal is put into a charging pan capable of holding it and sufficient cinder (squeezer or roll slag). The furnace being hot, the blast is shut off, the movable neck run back, two men hoist by a crane the pan with charge, and the puddler guides the pan into the furnace. The helper leaves the crane when the pan is elevated, and assists the puddler to turn the pan over when inside the revolving body, which deposits the metal and slag in the bottom. The neck is then run back into place before the furnace, the props are put up to keep it in place, the helper fires, puts on the blast, and the work is begun. The puddler and helper can now sit down for several minutes, until a fresh fire is needed, occasionally watching to see how the pigs are heating. In about fifteen minutes the furnace is partially revolved, just sufficient to turn the pigs, and the same thing is repeated several times, in all occupying about forty-three minutes from the time of charging. The pigs being partially melted, and all somewhat softened, the furnace is very slowly rotated, so as to prevent the unmelted pigs from knocking the lump fixing out; and also to allow the helper to break up, by means of a very heavy, short tool, any lumps of unmelted metal. Up to this period the operation occupies about fifty-nine minutes. After being sure that all the metal is thoroughly melted, then comes the thickening up of the metal, either by means of slag or water (we do not tap out our cinder as Mr. Danks did), after which a heavy fire is put on and the rotation of the furnace accelerated.

In a short time the metal is in a violent ebullition, or 'boiling very hard,' as some say. In about sixty-three minutes from charging and twenty minutes from melting, granulation has begun, and rapidly increases, so that in seven minutes more the iron has massed together and rolls and tumbles from side to centre, accumulating largely at every turn of the furnace. By this time the puddler takes a light tool, pushes straggling pieces from the movable neck into the revolving body, and then stops the furnace to arrange the iron ready for balling. A good fire is put on, and about three minutes are taken to more thoroughly heat the mass.

Then, by very slowly turning the furnace, the mass is carried up the side until its gravity causes it to gradually leave the side. The

engine is stopped, the puddler with a light paddle assists or retards the iron as he may wish, as it closes down or folds over the mass below, until the whole body of the iron is rolled together into a spongy, porous ball. If there is a cold side it is turned up to the heat, a fire put on, and the heat is made. When ready the ball is placed on one side by moving the revolving furnace about one-fourth of its course, the props are knocked away, a large fork elevated and (carried by a crane) introduced alongside of the ball, the furnace is moved a little and the ball rolls into the prongs, is swung out and carried by the crane to another fork, and thence by overhead railway to the squeezer. Thence it goes to the hammer, rolls or heating furnace, to be reduced to bar, bloom or slab.

If for blooms or slabs of ordinary size, it is taken from the squeezer, conveyed to the hammer, hammered flat, cut into suitable pieces, taken at once from the hammer while hot, put into the heating furnace, and, when heated sufficiently, returned to the hammer and hammered into bloom or slab of whatever size or shape desired. If for bars, the large bloom is rolled from the squeezer upon a lifting table elevated by steam to the height necessary, to be conveyed by a crane and fork to the heating furnace for a wash heat, or at once rolled off the lifter with the conveyers of my arrangement of universal mill, and rolled without further handling into a bar varying in width from ten to sixteen inches by any thickness desired, generally to three-fourths of an inch thick and twelve inches wide. If we should desire bars any narrower than the width given, I have introduced a machine whereby I slit the bar into any width wanted in the order of trade, from two to ten inches. If for plates or large piles, by means of three suspended hooks we lift the rolled muck bar to a second set of conveyers, run it to a set of upright shears of my designing and cut it into lengths of any number of inches or feet. Having proceeded thus far we take the cut sections by means of traveling fork to the scales and weigh; then, by a fork on wheels, we convey the iron to any point desired, where the labor for the time ends.

To do this work for ten furnaces we have a puddler and a helper to each furnace, one laborer to two furnaces; two men to convey the balls to the squeezer and assist at the rolls, and two men at rolls to cut the bars, lift them over, help to charge and draw at the furnace, weigh and place the muck bar; one man to furnish, fix and break lump ore; two men to break, weigh and wheel in the charges of

metal; one man to wheel cinder from the squeezer and rolls, and to clean up generally; one to work the ram at squeezer and do the pipe fitting about the furnace; a mason with one helper, and one man to oversee the whole.

As a matter of course, many persons who feel an interest in, as well as those who are curious about the Danks, and especially those who do not believe in the mechanical puddler, would think this short article very incomplete without something being said of its production, waste, and the coal and ore required to run it. I append a statement taken from our books of April and May of this year, as being about a fair average, though less in production than same months preceding:

Actual number of days worked	37
Number of heats made with nine furnaces, single turn	1,941

(Saturday we only make five heats per furnace.)

Amount of metal charged	1,746,900	lbs.
Amount of muck bar and croppings	1,693,010	"
Total loss	53,890	"
Percentage of loss	3.080	"

The amount of coal used for the above, including lighting, keeping up, melting fix, and all other requirements, is 40.34 bushels per ton of 2240 lbs. muck bar.

The amount of ore required for fixing in producing the above was 484.52 lbs. per ton of 2240 lbs.; the amount of scrap, 49.89 lbs. per ton of 2240 lbs.; amount of scale, 55 lbs. per ton of 2240 lbs.

This will perhaps surprise some who have heard other reports originating with Mr. Danks, but I give the facts as they appear on our books. It is only fair to say, however, that we have a quality of iron that defies comparison for regularity and strength.

The appended reports of Mr. P. F. Brendlinger, superintending engineer of the Point Bridge, Pittsburgh, and of Onward Bates, Esq., inspecting engineer of bridges and trestles for the Cincinnati Southern railway, and for the dredge boat building for Capt. Eads, for service at the mouth of the Mississippi, amply prove this point, namely, that to make a quality of iron necessary to meet the requirements of the times and trade, it is impossible to make a yield equal to the charge.

I do know, however, that by the process of work followed by Mr. Danks, and at first imitated by myself, even a greater yield was

attained, and can be at any time when desired; but I soon learned that that course was not calculated to give much reputation to the iron, and I abandoned it for my own method of work.

This, I think, will give all the necessary data, and enable any practical man to fully comprehend the value and, to some extent, the nature of the furnace. But it might be well for me just to remind the readers of this article that when we shall have completed the plant as originally designed, many of the figures will be changed, even more favorably to the furnace. For instance, I have just completed a furnace for melting the fix for all the furnaces, doing the melting in one furnace (constructed especially for that purpose) for repairing all.

When I say we can make a heat in about half the time we fix, and use much less than half the coal used for fixing, it can be readily understood how we can economize on coal; and when the smelting furnace, or cupola, is constructed and used, any one can see, from the time taken in melting, how much can be added to the production of muck, blooms or slabs by the use of melted metal in charging.

The time taken to work a heat of melted iron is much less than the time taken to melt it, and therefore it would seem very clear that the present product can easily be doubled, or even more; and it is also very clear that the period of melting is far more destructive to the furnace and fixing than at any other time, pointing clearly to the fact of the advisability of such a mode of procedure.

It might be asked, Why didn't we do it? In answer, I would say, that owing to the condition of trade since we have been fairly at work, our production has been sufficient to meet all our wants, and besides, we have had to overcome prejudices and to educate men to the work, as well as to school ourselves, and we have taken the conservative course of being sure that we are right before going ahead too far (as our English cousins did), and having to retrace our steps—but rather finding solid ground on which to put our feet, and when we moved keeping the position taken, knowing we were master of all we held. It has not been our purpose to make an unheard of yield and enormous output and then fizzle out or shut down for repairs or rebuild; but to make it pay as it went, and make the creature docile and subject to practical results.

Believing that there is some truth in the maxim that the race is not always to the swift, we have preferred to be the plodding turtle and win, rather than the fleet hare and lose.

But to all this I am very willing to add that all is not yet gained that will be by the mechanical puddler, even as a worker of metal or as to quality. As a boy and man I have gone through all the grades in a rolling mill, from a straightener in the small mill to catcher, heater and roller; from helper at puddling and boiling to puddler and boiler; thence to shingling or serving as hammerman at the old cast helve hammer, and I know whereof I affirm, for I know the burdens of all these branches of labor and the evils men in them have to endure. I have suffered their aches and hardships, and the hardest task I see in all this matter is to convince those whom I believe most interested, that in this process of work lies their best interest. The puddler under the common method is as a slave to his task; he has no heart when done, for aught else; mind and body are exhausted; no inclination remains for anything except it be to gratify his vicious passions, and sometimes he is too tired even for that. Here is a furnace which leaves him to exercise his faculties, saves his muscles measurably for other uses and fits him to appreciate and enjoy many of the rational pleasures of life after his daily labor. To these men I would say, and if it need be, cry aloud to capital: For pity's sake to let the old process die, as it ought, and take hold of the new, that we may labor less and enjoy more. Very many of the qualities peculiar to the Danks iron are now well understood and need not be described. By my way of operating the furnace, we have produced iron of such malleability as to be rolled into sheets varying in thickness from three thousand to eighteen thousand five hundred and fifty to the inch, as ascertained by weighing sections on chemists' scales. These were not exceptional cases with the iron, as specimens have been given to hundreds of visitors, both scientific and otherwise—manufacturers, engineers, mechanics, commissioners from foreign countries, as well as some of the more eminent men of our own country.

Bars of iron two inches by eight inches, and from one inch to three inches, round and square, have been bent double and hammered tight without a crack. Iron with fibre as fine as silk has been bent down tight after nicking with a chisel, and from the same stock iron has been made so granular as to appear like coarse steel. To the utter astonishment of competent engineers this has been bent down flat without fracture. I am not chemist enough to tell why it is. I only know that it has been done, and can be done at pleasure by certain manipulations now well understood by us.

Whether it is because of the peculiar motion of the furnace in contact with the metal, or from some other cause, I will not here pretend to say.

A theory has been put forth by Mr. Danks as to the taking out of the phosphorus and sulphur by the tapping of the cinder at a certain stage of the process.

Such may be the case, but one thing is very evident to us, and that is, we make iron equal, we believe, to any ever made by Mr. Danks, without tapping cinder out, and our success in the introduction of our iron into various uses settles the question as to the necessity of such a course.

I know that much I have said will appear as though I were more inclined to criticise and find fault with Mr. Danks than anything else, but I disclaim any such desire or purpose.

The facts are simply stated, and are not in accordance with what Mr. Danks caused people to believe. My opportunities have led me to develop more fully the faults and good qualities of the furnace which Mr. Danks believed to be so perfect, and yet lacking qualifications of practical value.

I think when fairly weighed it will be fully admitted that my efforts have done more for the future of the Danks furnace than Mr. Danks has himself accomplished. The fact remains, however, that the introduction of the general principle of machine puddling in a rotary furnace belongs to Mr. Danks, and, as I have said before, he merits better things than the iron interest of this or foreign countries have been willing to render to him. I herewith annex the tests made by Messrs. Brendlinger and Bates, and also tests made by Mr. Walker, of the Keystone Bridge Company, with a number of tests of our own at various times on our own machine, built by Riehle Bros., which, from all comparative tests with other machines, give the tensile strength from three thousand to five thousand below what it should indicate.

By reference to the tests made by Messrs. Brendlinger and Bates this will appear very clearly. It should be stated that the pig out of which this iron was made was a mixture of Isabella and an iron from the Mahoning and Shenango valleys and Red Bank.

The two first are red short irons made from Lake Superior ore with coke or bituminous coal and coke, and the Red Bank a cold short bituminous iron made from the native ores of the Allegheny valley.

PITTSBURGH, May 30, 1877.

John I. Williams, Esq., Superintendent Graff, Bennett & Co.'s Mill:

DEAR SIR:—Agreeably to your request that I would furnish you with the result of tests I have made of plates furnished by your mill for Captain Eads' iron dredge boat, I take pleasure in submitting to you the following statement:

Number of test.	Date of test.	Original section of specimen at breaking point.	Final section of specimen at breaking point.	Original area of specimen at breaking point.	Final area of specimen at breaking point.	Elongation in 6 in.	Load on specimen	Ultimate tensile strength per sq. in.	Percentage reduction of area.	Percentage elongation.	Specimen cut from.
	1877.	Inches.	Inches.	Sq. Inch.	Sq. Inch.	Inch.	Lbs.	Lbs.			
1	Mar. 12	1.875 x0.27	.....	0.506	.....	.....	25,750	50,890	....	....	¼ inch plate.
2	" 12	1.78 x0.27	.....	0.48	.....	.....	23,250	48,440	....	....	¼ "
3	" 12	1.6 x0.26	.....	0.416	.....	.....	21,500	51,680	....	....	¼ "
4	" 12	1.6 x0.27	.....	0.432	.....	.....	21,000	48,610	....	....	¼ "
5	" 12	1.75 x0.27	.....	0.4725	.....	....	22,500	47,620	....	....	¼ "
6	" 12	1.75 x0.27	.....	0.4725	.....	.....	22,500	47,620	....	....	¼ "
10	" 15	1.75 x0.48	.....	0.84	.....	.....	41,000	48,810	....	....	½ "
15	" 26	1.6 x0.37	.....	0.592	.....	....	28,500	48,140	....	....	⅜ "
16	" 26	1.66 x0.37	.....	0.614	.....	.....	30,750	50,080	....	....	⅜ "
17	" 26	1.5 x0.37	.....	0.555	.....	.....	28,030	50.450	....	....	⅜ "
18	" 26	1.54 x0.365	.....	0.562	.....	.....	28 000	49,640	....	....	⅜ "
7	" 15	0.875 x0.9375	0.69x0.73	0.82	0.504	1.875	45,750	55,790	38.5	31.25	Rolled to size
8	" 15	0.875 x0.9375	0.75x0.77	0.82	0.5775	1.75	45,500	55,485	29.5	29.2	"
9	" 15	0.875 x0.9375	0.70x0.73	0.82	0.511	1.75	45,750	55 790	37.7	29.2	"
11	" 17	0.9 x0.96	0.73x0.74	0.864	0.54	.....	45,500	52,660	37.5	....	"
12	" 17	0.9 x0.96	0.64x0.73	0.864	0.4964	1.875	44,000	50,925	42.5	31.25	"
13	" 17	0.9 x0.95	0.72x0.79	0.855	0.5688	1.5	44,750	52,330	33 4	25.0	"
14	" 17	0.89 x0.94	0.66x0.74	0.8366	0.4884	1.8125	44,750	53,490	41.6	30.2	"
19	April 9	0.9375x0.9375	0.75x0.75	0.88	0.5625	2.0	46,750	53,125	36.1	33.33	"
20	" 9	0.9375 x0.9375	.....	0.88	....	2.0	46,250	52,557	...	33.33	"
21	" 28	O 1¼in.diam	0.99diam	1.2272	0.7698	2.25	69,500	56,630	37.3	37 5	"
22	" 28	O 1 "	0.76	0.7854	0.4536	1.875	41,500	52,840	42.2	31.25	"
25	" 3	1.0 x0.38	.....	0.38	.....	.....	20,000	52,630	....	....	⅜ inch plate.
26	" 3	0.97 x0.38	.....	0.3686	.....	.....	20 500	55.620	....	....	⅜ "
27	" 3	0.97 x0.38	.....	0.3686	.....	.....	20,675	56.090	....	....	⅜ "
28	" 3	0.90 x0.38	.....	0.3762	.....	.....	20,675	54,960	....	....	⅜ "

Specimens were tested with parallel surfaces. Tests numbers 1 to 22, inclusive, were made with the Riehle testing machine at your mill. This machine, for some cause or other, appears to pull crooked, causing flat specimens to tear at one edge before the iron is strained to the greatest load it would carry if the stress was exerted through the longitudinal axis of specimen.

The effect of a cross strain is not so great with a round or square specimen, and for this reason I consented to test specimens 'rolled to size.'

Tests numbers 25 to 28, inclusive, were made with the Riehle machine at the Union Iron Mills. This latter machine I think to be nearly correct, as I have made numerous tests with it and had adopted it as my standard for other work.

In conclusion I will state that the iron I have received from your mill has been satisfactory. I can commend it for its cleanliness, its good fibre, and especially for its uniformity of quality.

Yours truly,

ONWARD BATES.

OFFICE OF RESIDENT ENGINEER,
POINT BRIDGE CO., 16 PENN AVENUE,
PITTSBURGH, June 5, 1877.

John I. Williams, Esq., Superintendent Millvale Iron Works:

MY DEAR SIR:—In answer to yours of the 1st inst., I would say that I am extremely sorry I cannot extend a report in full of all the tests of the iron produced by the Danks furnaces for the Point Bridge. I have been enabled to fill two large books with tests.

In all, over two thousand specimens have been tested, in size from bars one inch square to our largest links, 8x2 inches in section.

The specifications for iron to be used in the construction of the Point Bridge were very rigorous, demanding an ultimate tensile strength of 60,000 pounds per square inch sectional area, elongation 15 per cent., limit of elasticity not less than 25,000 pounds, the iron to be thoroughly fibrous, showing no fracture when bent cold 180 degrees, the test specimen to be $1\frac{1}{2}$ inch diameter.

All these qualifications were obtained from iron made in your Danks furnaces, save the ultimate strength, the highest figure reached being 57,000 pounds. As other manufacturers claimed to have reached this figure (60,000), the idea was conceived to compare testing machines; consequently a comparative test was made with the Keystone Bridge Company's machine, which was found to indicate, on an average, 10,000 pounds *higher* than yours, thus proving conclusively that the ultimate strength of iron depends on where the testing is done, and what kind of a machine is used. Your machine, I think, is a very good one, being a lever machine, measuring the strain applied by weights.

The specimens which thus reached 57,000 pounds on your machine answered all the requirements demanded by the engineers of the Point Bridge Company, except in one particular—the iron could be bent cold 180 degrees without fracture and hammered flat.

In fact, all kinds of twists and shapes could be obtained, but when a slight indentation or cut was made with a cold chisel and a blow given to the iron, the specimen would break off square, showing a thoroughly granular or crystalline fracture.

This feature of the iron was objectionable for bridge iron, and experiments were made for weeks to reach a better iron, until finally a quality was reached which was approved.

The ultimate tensile strength reached was 52,000 pounds on your machine, or about 60,000 pounds on the Keystone Bridge Company's machine.

The test of the approved iron was made on 1 inch square bars, and bars 1½ inch diameter, 3 feet long, with the following results: Ultimate tensile strength, 52,000 pounds per square inch; 27,000 pounds elastic limit; 24,000,000 pounds modulus of elasticity; elongation of specimen, 25 per cent. The specimens were bent when cold, either before or after fracture, 180 degrees, then hammered flat—the straight pieces were slightly indented with a cold chisel and bent cold 180 degrees, the fibres all remaining intact save those that were cut.

This same iron in the large bars, 8x2 inches in section, gave us 20,000 pounds elastic limit, and 26,000,000 pounds modulus of elasticity. The ultimate strength, and consequently the percentage of elongation, could not be ascertained, as the machine was not of sufficient capacity to break the bars.

The iron continued throughout all our tests exceedingly uniform. The final tests made were very similar in results to the first.

The last test was on the suspender rods, which were 9 feet in length and 1½ inch diameter.

The result was 27,000 pounds elastic limit; 24,000,000 pounds modulus of elasticity; ultimate strength about 54,000 pounds—52,000 pounds had been reached when a connection broke.

At a strain of 52,000 pounds per square inch the rod had elongated from 9 to 10 feet; the rod was removed and subjected to all imaginable bends, twists and contortions without breaking.

Having thus severely tested the Danks iron with such admirable results, I can safely say that it is not surpassed by any bridge iron made in the United States.

I can recommend it to all bridge builders with a great deal of pride, and I feel certain that a great many accidents would be prevented by using such iron judiciously.

Respectfully, yours,

P. F. BRENDLINGER,

Resident Engineer, Point Bridge.

Tests of Specimens of Wrought Iron for Messrs. Graff, Bennett & Co., made at the Keystone Bridge Works:

February 7, 1876.

Specimen	1	broke at	62,560	lbs.	per square inch.
"	2	"	60,956	"	"
"	3	"	67,372	"	"
"	4	"	71,382	"	"
"	5	"	70,847	"	"
"	6	"	68,441	"	"

February 8, 1876.

Specimen	0	broke at	68,441	lbs.	per square inch.
"	00	"	62,292	"	"
"	0	"	68,441	"	"

February 17, 1876.

Specimen	0	broke at	76,729	lbs.	per square inch.
"	0	"	74,056	"	"
"	00	"	77,531	"	"
"	00	"	74,590	"	"

J. W. WALKER.

As a matter of course a very great many tests, both as to bars and plates, were made while I was engaged with Messrs. Graff, Bennett & Co., of which a large number were recorded in a book kept for that purpose—to which I have now no access. But, even were they all transferred to these papers, they would only enlarge the record of facts already numerous enough to convince any fair minded person and give a greater variety of data as to the various uses to which the Danks iron is so well adapted: for instance, large plates were made by us for boiler tubes, for the National Tube Works, of McKeesport, which gave a tensile strength of 58,000 to 63,000 lbs.—and were made into tubes 14 inches in diameter, for which that establishment is so justly celebrated and so far stands

without a rival, at least in this country—and as far as my knowledge goes, surpassed by none anywhere.

I cannot close this article without alluding to one feature that deserves more than passing notice, and that is that while I may deserve some credit and Mr. Danks a great deal, the firm of Graff, Bennett & Co. should not go unnamed.

Without their progressive spirit, without their unstinted support by their confidence and pluck, where would the mechanical puddler of the United States have been to-day? And I might also with propriety say, Where would it have been in Europe? Our success gave them encouragement. Chattanooga, Indianapolis and Cincinnati, as well as all other places where they have been tried, have cast them to the dogs with many curses. So sick and sore at heart are those who tried them, that even now they would not believe, 'even though one rose from the dead' to testify that there is good in them.

It has required some nerve and backbone to go on against the gloomy outlook that rose before us. The general sentiment of the trade, encouraged by opinions from workmen and workers of iron, was against us.

Labor unions disseminated prejudices among all classes, based upon the idea of want of uniformity and rawness of body, and the failure first of one then another of the plants built for its development; then, finally, even where it had its birth—Cincinnati—a thousand rumors were flying about as to the causes of failure, but all against the furnace, and reports from Europe, gathering as they came, proclaimed defeat.

But amid all this, the principals stood firm; no word of despondency came to my ears, and no acts of theirs indicating want of confidence toward me was ever seen. On the other hand, when clouds seemed thickest and darkest they were most resolute and encouraging, and their words were: 'We must fight it through at all hazards. Go on; we'll make our point yet.'

Any one who has 'gone through the mill,' as the saying is, will know how essential it was to my success and success of the mechanical puddler, to have good backing. Without it failure would have been inevitable.

So, honor to whom honor belongs, and Messrs. Graff, Bennett & Co. are largely entitled to a share in whatever there is in the triumph and success now had, or which may hereafter be attained by the device known as the Danks Furnace."

It will be seen from the foregoing that my faith in our progress was undoubted. I claimed superior quality—increased production, and I now say less cost, even run as they were—and will now say that muck bar from the Danks furnace was made, including all labor, stocking, puddling, rolling, shearing, weighing muck bar, and piling it up ready for use in suitable lengths from 12 inches to 48 inches long—12 inches wide—at a cost of $4.80 to $4.90 per ton, and before I left Millvale, I believe I speak within bounds when I say, at a cost of $4.70 per ton of 2240. I will add just here, that up to the time I left Messrs. G., B. & Co., I had preserved the Danks department free from union men, and had full control, without dictation. Whether it was beneficial or not to have it so, is not essential for me to say here.

After all that has been said, I think I hear some one say—Well, if such results were attained why not go further? In another part of this paper a partial answer is given why. But I know there are those who are not satisfied with that, and some, I know, are aware of other reasons. So far as I was concerned myself, I had reasons to know that I could only add to others' interests by any further steps forward—only gaining to myself the empty honor of further improvement. As to what might be attained, I would refer to the results of the Danks furnaces at Creuzot, France. In 1875, while in Paris, I sought an introduction to the general manager of that establishment and was treated with very great kindness and regard, and while there, and at the works, gave freely my views and opinions as to the furnace, and after my return, sent sketches and information such as I have no doubt aided in their great success. In their operations I have always thought, and still think, that they made a mistake in the attempt of subdivision of the mass, by the construction of the furnace, and in confirmation of this, they wrote me asking as to the methods of handling heavy blooms, etc. Whether changes have been made or not I cannot say.

But it is possible the experience of our worthy President can give some light on this part of the subject, and I will leave this part of it for him to elucidate.

It has always seemed to me, from its inception to the present time, that the only successful way to work the Danks process was in mass, and by subdivisions afterwards, say, after squeezing, by hammering or rolling, and cutting. I am of the opinion that any and all attempts of subdivision in the furnaces only complicate the

matter, and I fear, result in difficulties which may lead to the condemnation unjustly of the furnace.

And now, in conclusion, let me say, that while much has been said favorably to the furnace in this article, something can be said against it. First, cost of construction; second, cost of maintenance; third, peculiarities of production.

As to the first, I hold that it would be useless to build a single furnace, without other suitable appliances for handling and working the product economically, and which could as well as not handle the product of 5 to 10 furnaces. To do this would require at least $100,000, in ordinary times, say for 5 furnaces and their equipments.

As to the second objection, I found that it required one furnace in 10 to be out for repairs, or in other words, a Danks furnace, worked as at Messrs. G., B. & Co.'s, is off work one-tenth of its time for repairs. But I am very well satisfied in my own mind that great changes can be made in this respect, and great gains made.

In my efforts to overcome one of the chief difficulties of the furnace, I adopted an English idea of a separate furnace for melting the fix or fettling, understanding they were successfully doing so. I constructed a furnace for that purpose, and made several efforts to avoid the time lost in fettling, but must confess to a total failure. Whether it was owing to the refractory nature of our ores (which I suspect), or a want of true conception, I don't know, but I found that by melting the fix it became adulterated with the liquefied brick and clay of the furnace, and besides, seemed to lose its qualifications of resisting heat in contact with melted metal, and that to such a degree as to make it entirely useless; and besides I found it took about as much fuel to melt the ores in this special furnace as it did in the Danks itself, so I had to abandon what I at first thought would be a great gain.

As to the third objection, I feel some embarrassment in attempting its discussion, for the reason that I am not so versed in the sciences as to give the various combinations productive of certain conditions, and to talk of atoms, carbon, oxygen, silicon, sulphur, phosphorus, etc., etc., and may only display such ignorance as to bring a smile to the face of those better versed in that direction.

But this branch of the subject deals almost wholly with chemistry, and no matter what my knowledge of that science may be, much of the interest involved lies in this peculiar feature, and I "perforce" must deal with it as best I can, and ask the indulgence of the Society in my behalf.

In my operations I used, as was very natural, such metals as I knew and were known as "inclined to cold short," "neutral," "inclined to red short," etc., and made my mixtures as my experience with the common puddling furnace dictated. But I found the product to differ from the product of the common puddling furnace. I soon learned that metals that were decidedly cold short produced fibrous iron, and, singular as it may seem, a mixture of metal which gave high tensile strength by reason of cold short metal, and which when broken would give a granulated fracture, in the ordinary furnace gave a fibrous condition and low tensile strength (in comparison) when worked in the Danks. I assumed that this arose from perhaps two causes—first, by elimination of phosphorus or silicon, or both; or second, by the constant contact with the oxygen of blast and ores. Let what may have been the cause, I have stated the facts, and in a few words can sum up and say in the operations of the Danks furnace the whole tendency is to run to fibre, no matter what mixture your metal may be, and the only difference there seemed to be was in the tensile strength, capability to stand heat, and the ductility of the iron in working when finishing.

I had been in the habit of mixing my metals to produce qualities of iron suited to what I wanted in the old method, but I found here differences which I could not at once fathom. It is true, I was making good iron, strong and fibrous, but I could not make the changes in character I wanted—it was fibre, fibre, fibre. I wanted some granulated iron, so that I could get greater tensile strength, and to better conditions for reducing, but mixing of my metal would not do it, and I was puzzled. I tried the cold short metal of the Allegheny valley, made from native ores—Red Bank, for instance. Many of you know how muck bar made from it would snap in breaking when made in a common furnace, and if worked down to an inch square how little elongation there would be, its high tensile strength and the sudden rupture on breaking. When worked in the Danks the product lost its hardness, became soft and ductile, but lost its strength and increased its power to elongate before breaking.

So I found throughout. The product, as a rule, became more fibrous, ductile and dense in body, increasing generally in strength and malleability than metals worked in the common furnace. I assumed this to be from several causes; first, the unquestionable

fact of its being better worked than possible in the common furnace, its constant contact with the oxide lining and the carbonic oxide flame, and not the least of all the large mass concentrated in one ball, which when reduced to bars, must of necessity reduce the fibre, expel foreign matters and condense its texture, molecules, or atoms. In my earlier workings I also found it almost impossible to combine carbon in the iron, but on the contrary found in breaking bars and in tests, both chemical and otherwise, the presence of graphite, uncombined. In all cases where this occurred the iron was very soft, bending like lead, but breaking at low strain (comparatively), elongating at least 30 per cent. Elastic limits took place at from 18,000 to 22,000 lbs., and breaking at 50,000 to 52,000 lbs. to the square inch. But after learning the secret of combining the graphite or carbon, we secured granular bars which, on reduction, gave us 28 to 33 per cent. of elongation, 24,000 to 28,000 lbs. elastic limit, and 55,000 to 68,000 lbs. ultimate strength; and eventually, in six trials that I made, I secured five solid homogeneous steel blooms, weighing between 700 and 800 lbs., which when reduced could be bent into any shape desired before hardening, and having all the characteristics of low steel. I cannot leave this subject, however, without referring to the fact that in the method of fixing as used by myself, Mr. D., and all others, we had as a result more or less ore in our iron, and wherever this occurred, as a matter of course, crude material was the result, and often spoiled plates and iron of that character. But I can see my way safely out of that trouble, as well as many minor ones not mentioned. As to product I can only say, with proper appliances it can be greatly increased over anything yet done at Graff, Bennett & Co.'s. To give you a clear conception of the possibilities I will say, that if a heat can be worked after melting in 28 to 30 minutes, what is there to hinder a furnace capable of working 1000 lbs. at a heat, making 16,000 lbs. in 10 hours work, or 30,000 lbs. in two shifts? I assert here that this can easily be accomplished; and more than this may be attained. If a furnace of a capacity of 2000 lbs. charge be built, as Mr. Danks claimed should be, and the Creuzot people I believe did, you can readily see what results can be accomplished. I know of nothing to-day connected with the iron interest which has been so unfortunate in forcing itself on the public mind, possessing such rare merits, as has the Danks furnace; for I assert without hesitation, that in output no furnace can begin to approach it. In cost of production,

even as now operated, it lessens it one-half. In quality, there is no method, save the Catalonian, that equals it, and in some respects it is inferior. In the lightening of labor, it is so superior that I have been amazed at the labor unions opposing it, and if for the sake of humanity only, it could become general, all other things being equal, it would be a boon to mankind. But the mechanical failures of its original construction; the prejudice and ignorance used in its first operations; their condemnation in Indianapolis, Chattanooga, and even at Cincinnati, its birthplace, coupled with the disappointing failures in England, it is no wonder the success of Messrs. G., B. & Co. is looked upon with suspicion and with doubt. It is needless for me to say here, that they are noways disposed to publish to the world their advantages.

But a furnace having the qualifications such as described, producing iron which, when rolled to 3 inches square, can be bent over and hammered flat without rupture, or reduced to sheets of the almost incredible thinness of 18,550 sheets to the inch, has merits which the iron interests of this age cannot afford to ignore. I know, when I speak of the extreme thinness given, it is apt to bring doubts, but in the many hundreds of specimens given out to the scientific world, there has been no denial of the figures. I am glad to say that in some very interesting and difficult experiments made by Prof. Langley, to solve the problem of solar heat, he found it necessary to use some of the thin specimens made of Danks iron (all other metals and alloys failing the purpose), and found it met all the requirements of his experiments, and to gratify his curiosity and satisfy himself, took very careful measurements, and the specimens he had measured over 10,000 sheets to the inch thick. I will also say that but two perfect sheets out of 160 were had, and sent to the U. S. Government Department at the Centennial Exhibition, along with a bloom weighing 1994 lbs., muck bar 1834 lbs., and sections of rolled iron (bent) from 3 inches to 1 inch square, and the thin sheets mentioned, viz.: 18,550 to 1 inch. (I quote weights from memory.)

As a finale let me say, that in this day of progress any one who has the means, and owning a blast furnace, by the erection of a proper plant of Danks furnaces, with the necessary auxiliaries, can make iron at a price and of such a quality that neither a reduction of tariff or home competition need alarm him, and in the progress of time and its teachings, much that is now a sealed book on the

working of the Danks furnace will be revealed, to its further advancement and its permanent adoption.

DISCUSSION.

P. F. Brendlinger. When I took charge as Resident Engineer of the Point Bridge, I found the specifications were very rigid for the quality of iron to be used in its construction—the requirements being that the iron was to be ductile and thoroughly fibrous, and stand the following tests: To have an ultimate strength of 60,000 lbs. per square inch *without* a fracture; an elastic limit of 25,000 lbs. per square inch; a bar 1½ inches diameter to be bent, when cold, 180 degrees without a fracture, and other tests which are not essential to be mentioned.

These requirements, when it is considered that the test specimens were all to be in shapes as used in square or round members of the bridge, would make any iron man tremble, for they certainly are crowding into low steel. However, I determined to see how near Mr. Williams could come to the mark. I tested specimens almost every day for nearly six weeks in the Millvale mills of Graff, Bennett & Co. At first the iron was thoroughly granular, with scarcely any elongation, breaking at 42,000 pounds per square inch. This iron was all condemned. The best we could do in the ultimate strength was 52,000 lbs. per square inch, which iron was an exceedingly good iron, coming up to the specifications in every particular except the ultimate strength. I believed the testing machine was wrong, and by request the makers, Riehle Bros., Philadelphia, were asked to have the machine examined; but as they could not attend to it for at least a month, I determined to have test specimens sent to other machines in Pittsburgh. I had some iron rolled in long bars 1 inch square and 1 inch round; had each piece cut into lengths of twelve inches, then sent three or more to the Keystone Bridge Company's works, the same to Anderson & Co., and kept the same quality at the Millvale works. The results obtained at the Keystone and Anderson & Co.'s ranged from 5000 to 10,000 lbs. higher than we could obtain at the Millvale works. A great many outside tests were thus made, and all went higher than the home machine recorded. I felt convinced that Graff, Bennett & Co.'s machine was wrong, as it did not seem to pull straight, (the machine was subsequently found to be out of adjustment). The test shown in Mr.

Williams' report as made by the Keystone Bridge Company varied from 60,000 to 76,000 lbs. per square inch. The test specimens running over 70,000 lbs. were in groove shapes according to sketch, which accounts for the high ultimate strength. This same iron on the home machine (G., B. & Co.) had an elastic limit of 25,000 lbs. per square inch; an ultimate strength of 60,000 lbs. per square inch; plain cylindrical specimens a modulus of elasticity of 26,000,000; could be bent in any shape when cold, without fracture; elongate 25 per cent. in lengths of 18 inches, and when bent cold the two ends could be flattened close together without a sign of a fracture. This iron seemed to fill the bill. I experimented further. I took a number of the broken pieces returned by the Keystone Bridge Company; I bent one piece of each pair originally belonging to the same test pieces, bent it when cold 180° and flattened together with a sledge or steam hammer without a sign of a fracture. The other piece I had nicked with a cold chisel and tried to open out the fibres by bending, but the specimen always broke with a square fracture, showing a thoroughly granular fracture. I found that all the specimens acted the same way. I did not consider this the iron wanted for such an important structure. Mr. Williams was again called upon to exercise his brains to make iron that would stand to have the surface cut and show fibres when bent. This was tried a long time and the requirements were filled except the ultimate strength. The iron that was obtained and subsequently used in the Point Bridge gave the following results in Graff, Bennett & Co.'s machine:

Ultimate strength.....	52,000 to 54,000 lbs.
Elastic limit.....	27,000 "
Modulus of elasticity	24,000,000 "
Elongation in twelve inches....	25 per cent.

Could be bent when cold 180° and flattened together. When nicked and bent the fibres opened out like the finest kind of hickory wood. This iron gave an ultimate strength of 60,000 pounds in the Keystone machine. The iron was remarkably uniform, as the 2100 tests which were made during the construction of the bridge will show. When the manufacture of the iron was about closing I took two suspender rods, each 9 feet long, 1½ inch diameter. Result:

Ultimate strength.....	57,000 lbs.
Elastic limit.....	27,000 "
Modulus of elasticity.....	25,000,000 "

When the rods were taken out of the machine they measured 10 feet, an increase of over 11 per cent. I then bent the rods double, and flattened them together with a steam hammer without showing any sign of fracture. I took one piece, nicked it with a cold chisel and bent it, the fibres opening out beautifully.

I took several specimens of this iron on a tour to Boston, Providence, Brooklyn, New York, etc., showed it with the records to various iron men and engineers of prominence, and they were all astounded with the results.

In conclusion, I can only say that Mr. Williams deserves more credit than he has ever received for his indefatigable labor in making such excellent iron from what was previous to his attempt a stubborn old furnace.

C. L. Strobel. I wish to offer an explanation of the high results obtained by the use of the Keystone Bridge Company's testing machine. This machine is a hydraulic testing machine in which a certain amount of friction has to be overcome to move the plunger, whether the specimen which is being tested is large or small. If the specimen is large, this friction is a small percentage only of the total pull on the specimen; if small, it will be a large percentage. A comparison of the results obtained by breaking pieces of the same rod in the Government testing machine at the Watertown Arsenal and in the Keystone machine, shows an absolute difference of 2600 lbs. This will represent the value of the friction to be overcome in the Keystone machine, if the Watertown machine is assumed as absolutely correct. If it may further be assumed that this frictional resistance is a constant quantity not changing with the intensity of the pressure, it will be seen that while the Keystone machine will give practically accurate results for large size bars, it will give results considerably too high for small specimens.

BLASTING.

By Arthur Kirk.

[Read October 19, 1880.]

In this age of improvement I know of no important industry in which so much hard labor and money is lost for want of intelligent study and use of modern improvements, as in the simple operation of blasting.

When you bear in mind the fact that blasting of minerals lies at the very foundation of all that distinguishes civilized from barbarous life, you will at once admit that its importance makes it well worthy of our attention.

You are all aware that the houses of civilized men are very much superior to those of the barbarous races. The first point of difference is in the foundation, and almost the first things needed for the foundation of a house for civilized man are powder and blasting to get stone for the foundation.

Another point of superiority of civilized life is the abundance of manufactured iron and glass; yet I think that not one pound of all the immense quantities of these articles manufactured around Pittsburgh is obtained without drilling and blasting to prepare either the coal, iron ore, limestone or sand used in its manufacture. But the very nature of the work of quarrying seems to draw to it many men of one idea, who work hard and think little; who having made holes in rocks for many years, insist, therefore, that they know all about blasting and persistently oppose all modern improvements.

Many farmers are living yet who have cut many harvests with a sickle, before the days of cradles, mowing and reaping machines, etc. These might with the same propriety resist the use of mowing and reaping machines because they know all about farming.

Another reason why improvements are not introduced in blasting is, because the owners of mines seldom give any personal attention to blasting, but leave it all to John or Pat, who seldom takes any

interest in improvements, and is often prejudiced against them and condemns them without a trial.

The subject of blasting may be divided into three divisions:

1. The hole and how to make it.
2. The explosive used.
3. The manner of firing the charge.

1. *The Hole and How to Make It.*—The common way of making the hole is by either churn or jumper hand-drills. Three men usually form a gang and the gang make from eight to twelve lineal feet of hole per day in hard rock.

By either of these modes it is practically impossible to make a round hole—generally a three-cornered hole being made—which is very objectionable, because, if the hole is perfectly round it will present a uniform circular surface to the pressure, and retain the blast until its force is fully developed. But with a three cornered hole the pressure on the long sides of the hole is concentrated at the corners, which being required to resist more than their share of the pressure, give way and permit the explosive gases to escape before their force is fully developed, and only a large amount of smoke is produced.

A much better plan is to have the holes made by machinery; this secures a cheaper and better hole, being perfectly round, and thus retains the explosive gases until their power is perfectly developed and do more execution on the rock and with less smoke. In close or underground work where the air is bad, this is found to be of great advantage. With the latest improved steam drills a gang of three men often make from seventy-five to one hundred feet of hole in one day.

DRILLING BY STEAM OR COMPRESSED AIR.

This shows the drill completed and ready to have the steam or air hose screwed to it at the throttle valve, then by opening the throttle valve *A* the machine will start, and strike from 100 to 200 strokes per minute. As the rock is cut away, screw down the cylinder by turning feed-screw *B*.

2. *The Explosive Used.*—Explosives may be divided into chemical and mechanical combinations.

Chemical explosives embrace what are known as nitro-glycerine, gun cotton, dynamite, dualin, hercules, Ditmar powder, rend rock, mica powder, etc.

These are produced mainly by the combination of nitric acid, sulphuric acid and fatty matter, or glycerine, with cotton, tanbark, paper pulp, saw dust, soda, mica scales, pulverized charcoal, etc., as absorbents.

These will explode under water, which makes an excellent tamping. Most of them are unfit for sporting or military use, because their explosion is so instantaneous it ruptures the gun before the ball can start. Their force is more like the blow of a large sledge whose force is spent in an instant, while the explosion of black powder is more like the action of a powerful spring which starts the projectile more slowly and continues to propel it until it escapes at the muzzle of the gun.

The manufacture of chemical explosives is of comparatively recent date and in many cases is as yet imperfectly understood. Many alarming accidents have occurred in the handling of some of them, which has given a bad name to the whole family. But enough is now known about some of them to prove them to be perfectly safe when properly understood and handled, and very profitable in certain kinds of blasting.

Mechanically combined explosives are common black powder, carbo azoteen and mahoning powder.

These are composed mainly of saltpetre or nitrate of soda, sulphur and charcoal, or tanbark.

All of these ingredients are first finely pulverized separately and then mixed in certain proportions and incorporated by being run under heavy wheels or rollers for from two to six hours, so as to mix uniformly and bring a certain proportion of each ingredient in immediate contact with the other ingredients.

The mass is then generally submitted to strong hydraulic or screw pressure, and then is called pressed cake. Then it is crushed

by corrugated rollers and by means of sieves separated into the different sized grains of blasting, sporting or military powder, each of which has its peculiar mark or name.

Carbo azoteen is made by boiling these ingredients together, and has never been a success.

Mechanically combined explosives must be kept perfectly dry; even a slight degree of dampness injures them.

As a rule, the finer the grain the quicker the explosion and the smaller the charge. While for large blasts in rock, powder is now used to good advantage in grains as large as grains of corn, and in large artillery charges still larger grains are used, called Pebble Powder. We now come to the—

3. *Mode of Firing the Charge.*—Three modes are used—squib, fuse and electricity. Squibs are made of about six inches of rye straw filled with fine powder, and are used principally in coal blasting. The hole being drilled horizontally three to five feet into the coal, a charge of eight to twelve inches of FF blasting powder is generally put in, then an iron rod 5-16 inch in diameter, called a needle, is inserted in the hole back to the powder, then the hole is tamped full by having dry clay or sand pounded solid into it, and the needle is withdrawn, leaving an open passage like a pipe through the tamping to the powder. The squib is inserted in the mouth of this hole and a slow match applied to the outside end—the recoil of the powder burning in the straw throws the burning squib back along the needle hole or pipe to the powder chamber and the explosion takes place. This mode of firing can only be used in horizontal holes.

Fuse consists of a thread of black powder incased in a wrapping of tarred hemp, and called hemp fuse—or in a wrapping of cotton, and called cotton fuse—then to make it water proof a tarred tape is wrapped spirally around it and then it is called single tape fuse,

and will resist dampness a long time—or a double wrapping of tarred tape is wrapped around it and called double tape fuse, which will burn and fire a charge of powder under 20 feet of water.

In all of these fuses there is a central cotton thread which has been saturated with saltpetre, which makes it continue to burn when it would otherwise go out. In open air this will burn at the rate of three feet a minute. Every precaution is taken to make the fuse continue to burn until the fire reaches the powder and the explosion is produced. But from some cause or another holes sometimes hang fire and are a source of great danger to the miner or quarryman. Holes thus charged, which ordinarily should explode in from one to three minutes, have been known to hang fire for twenty-four hours and then explode.

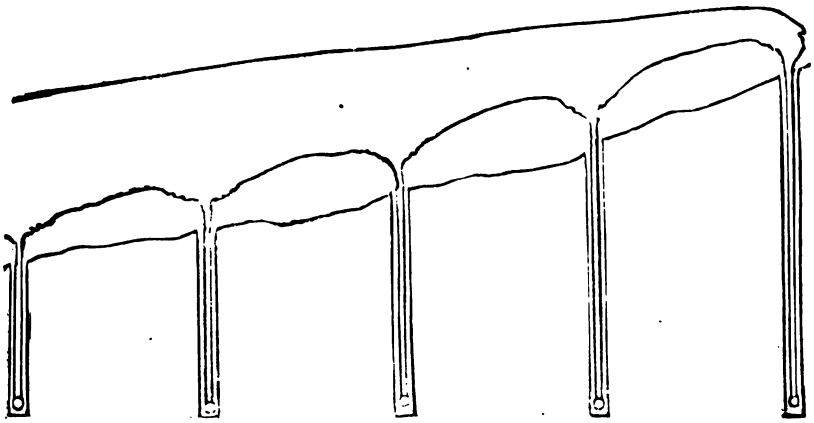
The third mode of firing is by electricity. When using it, the hole, the charge and the tamping are the same as in firing with a fuse, but instead of inserting the common fuse already described an electric exploder is used, which is made thus:

ELECTRO FUSE.

A copper cap, ¼ inch diameter and about 1 inch long, is filled one-third full of fulminate of mercury, into which is inserted the ends of two insulated copper wires connected by a small thread of platinum wire, and the end of the cap is then closed by means of melted sulphur, making it water proof. Electric fuses are made 4, 6, 10 and 15 feet long, with about two inches of the outer end stripped of the insulation and tinned.

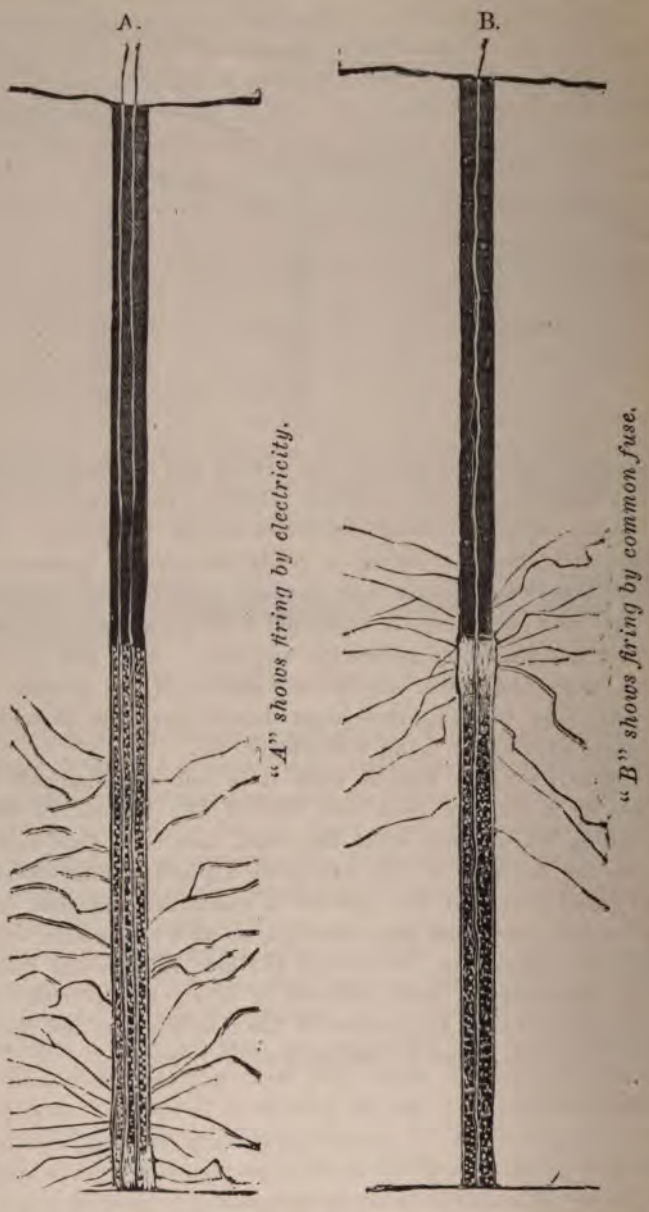
In using them the blaster selects an electric fuse long enough to reach the bottom of the hole and leave a few inches out of the hole, then puts in enough powder to cover the bottom of the hole one-half inch deep, then his exploder, then one-fourth less powder than if fired with a fuse, and tamps the hole the same as with ordinary fuse; any number of holes may be thus prepared, of equal or unequal depth or distances apart.

Directions for Firing.—One wire of the first hole is now connected to one wire of the second hole and the remaining wire of the second to one wire of the third hole, and so on until all are



connected; there will then be one wire of the last hole and one wire of the first hole left unconnected. These wires are then connected by means of long conducting wires to the battery at a place of safety, and when everything is ready the circuit is closed and the small thread of platinum wire in the bottom of each hole becomes red hot and each cap is exploded with great force at the same instant, and each hole assists its neighbor. And thus by simultaneous explosion, with only three-quarters of the powder used in ordinary fuse blasting, more than double the rock is moved with the same drilling by firing with electricity.

In quarries where fuse is used it is not uncommon to find six inches or a foot, or even two feet of the bottom of the holes remaining unruptured after the blast has been fired and cleared away—the drilling of the unexploded piece of hole was so much hard labor lost and the powder it contained was lost, for if the powder had done what was intended, no part of the hole would have been left unexploded. No part of the hole is thus left unexploded where electricity is used, because in firing by electricity the first point ruptured is at the bottom of the hole and the full force of all the explosive is spent in enlarging the rupture.



For profitable blasting by either mode of firing, the bottom of the hole in open work should be at least one-tenth less from the open

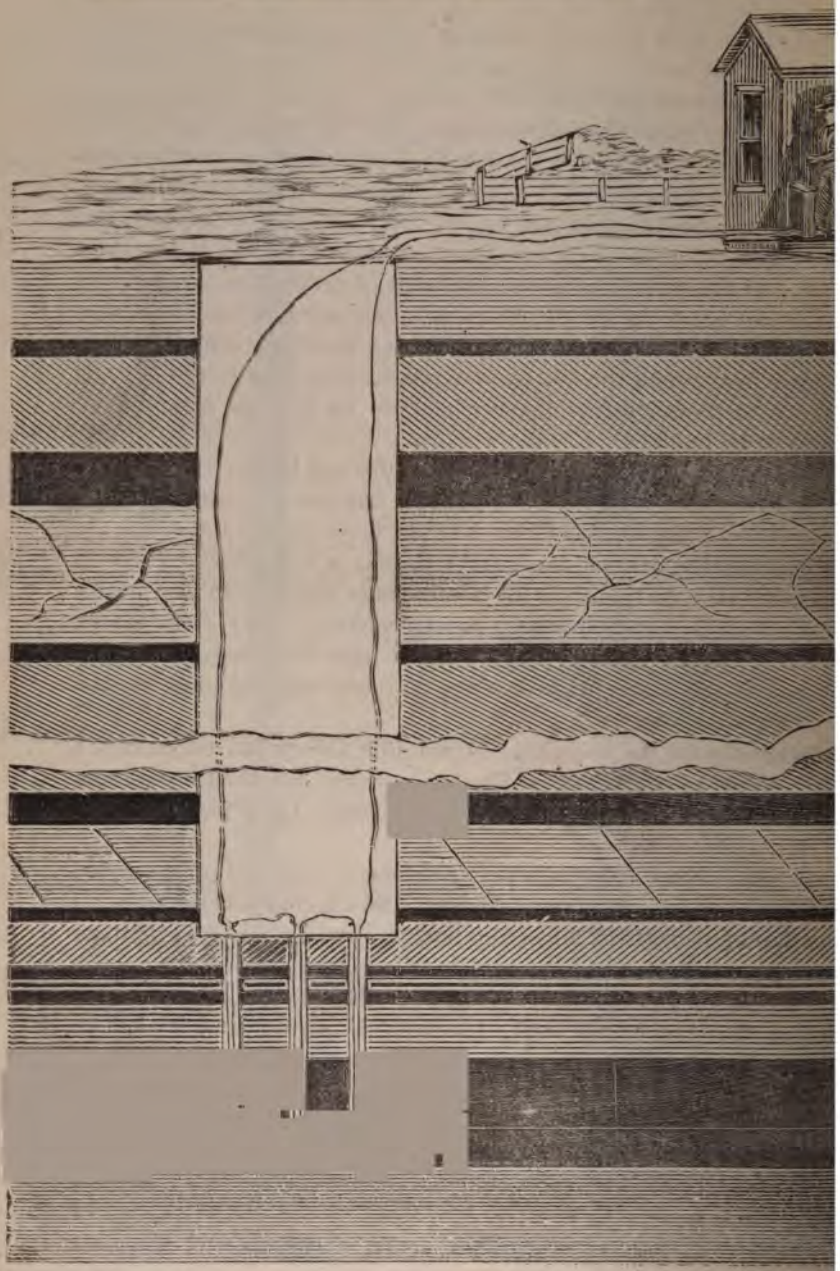
front of the rock than the depth of the hole; thus if the hole is ten feet deep the bottom of the hole should not be more than nine feet from the face of the rock, and in some rock not more than eight feet, so as to make the bottom of the hole the weakest part of the blast. But if the hole is ten feet deep and filled up four feet with powder and fired with a fuse at the top of the powder, there will only be six feet of rock on top of the first point of rupture, and there being nine feet in front of the hole makes the top the weakest part, and the result is a great discharge of projectiles through the air to the great danger of all around, and much of the material is lost; but if the same single hole had been fired by electricity at the bottom of the hole, the bottom rock would have been forced out and the top rocks would tumble down and do no damage, and all be in place to be handled.

The contrast between firing with a squib and by electricity is still greater, because a fuse may sometimes burn to the bottom of the hole before firing the blast, but a squib must always fire at the top of the powder, and as the needle hole is a full quarter inch in diameter, the first blast is a jet of orange flame from the needle hole, which is partly consumed powder and cools into dense smoke to the great annoyance of the miner; in light work only the top is blown off the hole, the first point of rupture taking place at the top of the powder.

In conclusion, to show this is not idle theory but actual fact, I may point to the shaft sunk this summer for the Chicago and Connellsville Coke Co., near Uniontown, under the superintendence of Mr. James Harrison.

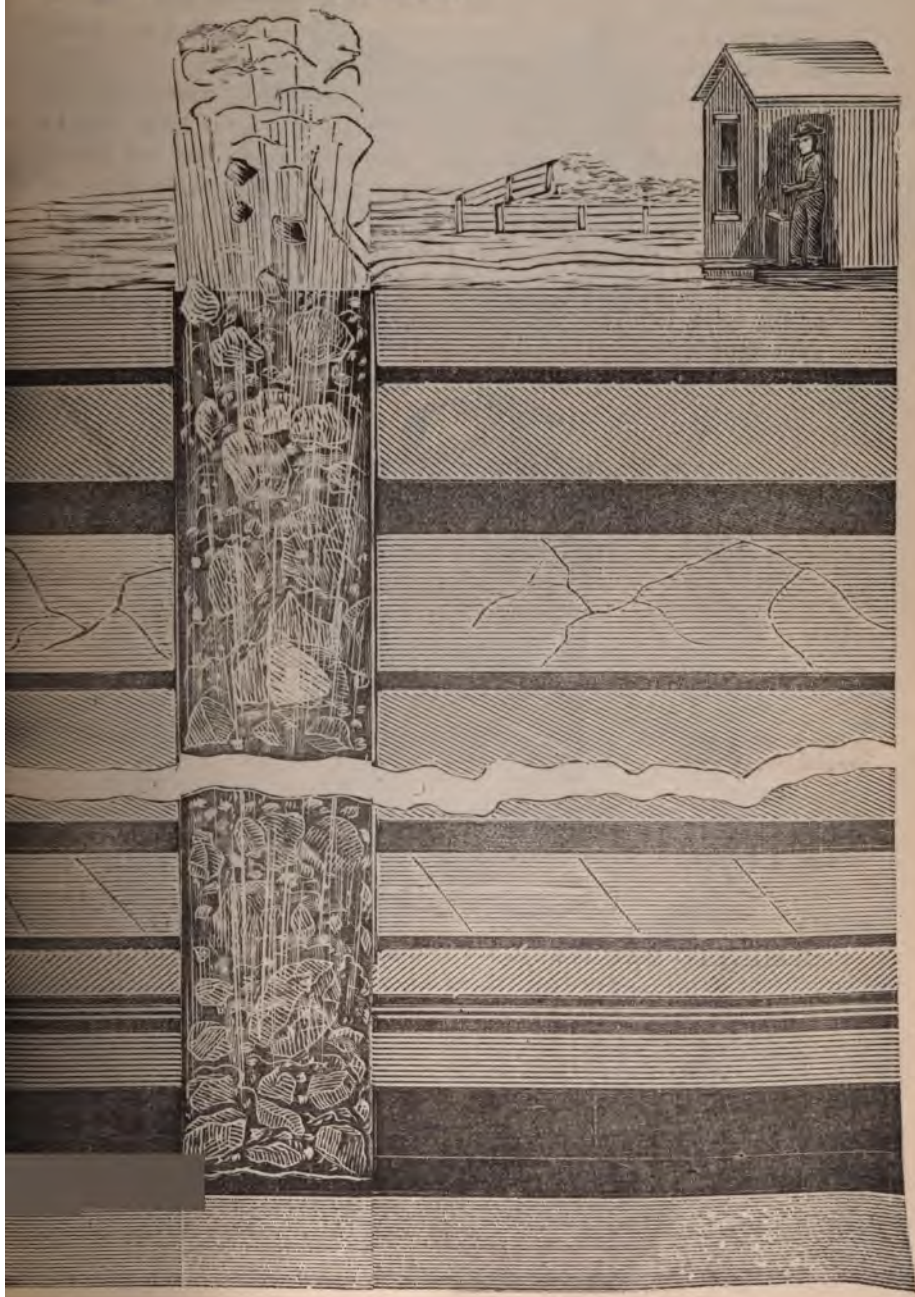
Mr. Harrison has had great experience in everything connected with modern mining improvements, and on commencing work on the shaft procured the latest and best improved steam rock drill, an electro-magneto battery and safe chemical explosives, and with the assistance of Mr. Thomas, an experienced Welsh shaft sinker, he broke ground about the 15th of last March, and two weeks ago he had sunk the shaft 325 feet to the coal; has got his ovens and all his buildings up, and I presume is now making coke, which under the old plan of sinking he could not have done before next April.

I can also point to the shaft now being sunk by Mr. J. K. Taggart for E. K. Hyndman, near Connellsville, and to another near the same place, now being sunk by Mr. Hopkins for Mr. Wickham, of Connellsville, both of whom are using electricity and chemical explosives to good advantage.



The above cut represents a blast of three holes, each six fe
deep, ready to fire in the bottom of a shaft that may be man
hundreds of feet deep. As soon as the operator in the house pushe

down the operating rod, all the holes will fire simultaneous, and the result will be as shown by next cut.



The preceding shows a blast fired by electricity at the bottom of a shaft, by which all the holes are fired simultaneously and at pleasure by the operator in the house above ground, which is far safer than fuse firing, as the operator has full control and need not fire until every man has come up and all are safe.

I may further add, that theoretically blasting by electricity has been known to engineers for thirty or forty years, for large blasts such as Hellgate. But it has only been within the last few years that the apparatus has been made so simple and portable as to be of any practical benefit in quarry work. It has now been made so simple and is so easily handled, that a youth can take the apparatus out of the tool box, lay down the cable to a safe place, charge five or six holes, tamp and fire them and take up the cable and replace apparatus in tool box, all inside of twenty minutes.

MAGNETO MACHINE, 5 x 8 INCHES AND 14 INCHES HIGH.

A STUMP BEFORE BLASTING.

SAME STUMP AFTER BLASTING.

Removing stumps by hercules does the work much quicker and cheaper than any other plan, and leaves the ground in better condition, as the subsoil is not dug up and mixed with the surface as is the result of digging out stumps.

THE

BASIC DEPHOSPHORIZING PROCESS

WHAT IT IS, AND WHAT MAY BE EXPECTED FROM IT.

By Jacob Reese.

[Read December 21, 1880.]

A slag is said to be basic when it is composed of metallic oxides; or, in other words, when the base of the slag is a metal the slag is said to be basic. Oxide of iron, and oxide of calcium, are true basic oxides, and form highly basic slags.

A slag is said to be acidulous when it is composed of a metalloid such as silicon, phosphorus or sulphur, oxidized to silicic acid, phosphoric acid, or sulphuric acid, and these acids combine with a base forming silicates, phosphates, or sulphates. When these compounds are present in a slag in a large degree, it is said to be of a highly acid character.

When a metallic process is conducted in the presence of a highly basic slag, it is called a basic process; and when it is conducted in the presence of a highly acid slag, it is called an acid process.

The process by which the ancient Romans and Britons made their iron, is known as the Catalan process. It was conducted in an open chamber surrounded on all sides and the bottom with a lining of charcoal dust. The fuel was used in this metal chamber admixed with the iron ore and metal. The slag present in this metal chamber and produced by this process was principally composed of oxide of iron; hence the Catalan was and is a basic process.

The blast furnace is lined with stone or brick, both of which are highly acidulous; and although limestone is used as a flux, owing

to the silicious character of the ore and ash of fuel, the slag is of an acid character, as will be seen by the following analysis:

Silicic acid	58
Lime	23
Alumina	8
Magnesia	2
Manganese	–
Oxide of iron	9

Hence the blast furnace process is an acid process.

Henry Cort, who invented the puddling process, was the first to separate the fuel from the metal chamber; he lined his metal chamber with sand (silicic acid); the slag was highly acidulous, and Cort's puddling process was an acid process.

Dr. Roebuck, the inventor of the refinery fire, lined the metal chamber with cast iron water boshes. The fuel was admixed with the metal. The refinery slag was highly basic, as is shown by the following analysis:

Oxide of iron	85.0
Silicic acid	14.0
Alumina	0.5
Magnesia	0.5

Hence the refinery process was a basic process.

Samuel Rodgers improved Cort's puddling process by putting an iron bottom and iron plates into the puddling furnace, and lining the metal chamber with oxide of iron instead of sand. The following analysis of the slag shows it to be highly basic:

Oxide of iron	89.0
Silicic acid	9.0
Alumina	1.5
Magnesia	0.5

Hence Rodgers' puddling process is a basic process.

The Bessemer process, invented by Henry Bessemer, is conducted in a converter which is lined with gannister (a highly silicious substance). The slag produced is composed of the following:

Silicic acid	44.30
Lime	.65
Protoxide of manganese	24.55
Alumina	10.80
Magnesia	.25
Oxide of iron	19.45

It is a silicious slag because there is not sufficient basic material to engage all the silicic acid as silicates. And the Bessemer process is an acid process.

In the open hearth process the metal chamber is lined with sand. When metal and scrap are used the slag is highly acidulous; and the metal and scrap open hearth process is an acid process.

When iron ore is used in the open hearth in considerable quantity, the slag is neutral; and the ore and metal open hearth process may be classed with the basic processes. We therefore have as

Basic Processes:	*Acid Processes:*
Catalan,	Blast furnace,
Refinery,	Cort's puddling,
Rodgers' puddling,	Bessemer,
Open hearth ore and metal.	Open hearth metal and scrap.

The dephosphorizing problem may be summed up in these words: The phosphorus must be oxidized to phosphoric acid, P_2O_5, in the presence of a basic slag, in order that the acid so formed may unite with and be held by a metallic base as a phosphate of lime, or a phosphate of iron. And as silicic acid decomposes a phosphate of lime or a phosphate of iron, and carbonic oxide decomposes a phosphate of iron, the slag must be of a highly basic character in order that all the silicic acid formed by the oxidation of silicon shall combine with and be engaged in the slag as silicates. And in order to avoid the reduction of the phosphate by carbonic oxide, the dephosphorization must take place in the presence of a highly basic slag, and in the absence of carbonic oxide.

In the acid processes before mentioned, as the blast furnace, Cort's puddling, Bessemer converter, and the open hearth with metal and scrap, the silicic acid and carbonic oxide reduce the phosphate to a phosphide; and as a phosphide has a greater affinity for the metal than for the slag, the phosphorus is returned to the metal.

In the blast furnace, however, an additional reaction takes place under the following conditions: Carbonic oxide being always present at the zone of reduction, where the ores are deoxidized, the phosphorus accompanies the metal as a phosphide of iron. In case where the slag in the hearth does not contain over 40 per cent. of silicic acid, and does contain 60 per cent. of basic material, the silicic acid being held as silicates, the oxide of iron contained in the

slag in the free state will oxidize a portion of the phosphorus, which, uniting with oxide of iron, or lime, will form a phosphate of iron, or a phosphate of lime, and exist in the slag in the hearth of the furnace below the zone of carbonic oxide; under these conditions a partial dephosphorization of metal takes place in a blast furnace working on black cinder. The degree of phosphorus thus taken up by the slag will depend upon its basic character and its ability to hold the phosphorus as a phosphate.

In the old basic processes—the Catalan process and the refinery process—the fuel being admixed with the metal, carbonic oxide was always present; hence the phosphate could not exist, even in the highly basic slag, and dephosphorization was impossible. In the basic open hearth dephosphorization takes place before the elimination of carbon commences, if the phosphoritic slag is removed; and also after the carbon has been consumed and carbonic oxide disappears.

In Rodgers' basic puddling process the chemical reactions are divided into three periods; first, the melting period; second, the boiling period; third, the solidifying period.

During the first period the metal is melted and the oxide of iron is admixed and melted. The chemical reactions which occur in this period are the oxidation of phosphorus and of silicon, and their removal from the metal to the slag. As there is no gas evolved from the oxidation of these elements the metal remains in a state of rest, except so far as agitated by the puddler's tools. If the slag be tapped off just before the close of this period, it will be found to contain from 70 to 80 per cent. of the phosphorus previously contained in the pig metal. But if the slag remain with the metal until the silicon is reduced down to .02 the second period commences, the carbon is oxidized to carbonic oxide, which, passing upward through the slag, attacks the phosphate and reduces it to a phosphide, and, as a consequence, all the phosphorus removed from the metal during the first period (and permitted to remain in the slag), is returned to the metal during the second period. As the chemical reaction during the second period is the oxidation of carbon to carbonic oxide (C. O.), ebullition takes places, and the metal boils. When the carbon has been reduced down to .08, the ebullition ceases, the cinder or slag "drops," and the metal solidifies, and, as the puddlers term it, "is brought to nature," during the third period.

During the first part of the third period the damper is raised, and the metal which extends above the slag is exposed to an oxidizing flame. The phosphorus is either sweated out of the metal by liquidation or is oxidized by the fluid cinder; in either case, it being oxidized to P_2O_5, it again enters the slag as a phosphate of iron ($2FeO.P_2O_5$). There being no free silicic acid or carbonic oxide in the slag during this third period, the phosphorus remains in the slag until the metal is withdrawn; hence Rodgers' puddling process, when properly conducted, is a true basic dephosphorizing process, being conducted in the presence of a highly basic slag, and in the absence of C. O. or free silicic acid.

As phosphorus, silicon and carbon tend to reduce the fusion point of iron in degree to the amount of these elements which the metal contains, it follows that the fusion point of iron is greatly raised by the diminution of these elements, and this is the reason that the iron solidifies during the third period of the puddling process.

In the Bessemer and open hearth processes the temperature is kept high enough to hold the metal in a fluid condition after the elimination of phosphorus, silicon and carbon, but at the high temperature required, Rodgers' basic lining (oxide of iron) is fused also, and for this reason the Bessemer converter and the open hearth have heretofore been lined with a silicious material.

The new basic dephosphorizing process, by which iron and steel may be desiliconized, decarbonized and dephosphorized, and yet be retained in a fluid state, so as to cast it into ingots of iron or of steel, is conducted in a metal chamber lined with lime, which is a basic material, it being the oxide of the metal calcium. By means of a lime lining, the required temperature to keep the metal fluid may be employed with but little waste of the lining; and when the lining does waste, it being of a highly basic character, it tends to form a highly basic slag.

When the Bessemer converter is furnished with a lime lining, and the metal is blown in the presence of a highly basic slag until the silicon is oxidized to silicic acid, and this acid unites with bases forming silicates, and the blow is continued until the carbonic oxide disappears, and the metal is further blown in the presence of a highly basic slag, and in the absence of free silicic acid and carbon oxide, the phosphorus is rapidly oxidized to P_2O_5, which enters the slag, and uniting with oxide of iron, remains there as a

phosphate of iron ($2FeO.P_2O_5$), and the silicon, carbon and phosphorus are entirely eliminated from the metal. When the slag is of a highly calcareous basic character, the phosphate of iron may be decomposed and a phosphate of lime formed ($CaO.P_2O_5$).

When the phosphorus exists in the slag as a phosphate of iron, if carbonic oxide be present, it will rob the phosphate of its oxygen, forming carbonic acid, and the iron and phosphorus unite as a phosphide of iron, and return to the metal. But when the phosphorus exists in the slag as a phosphate of lime, carbonic oxide will not reduce it. If, however, silicic acid is present in a free state, it will rob the phosphate of its base, forming a silicate of lime, and the carbonic oxide will rob the acid of its oxygen, and the phosphorus is returned to the metal.

In the practice of the basic dephosphorizing process in the Bessemer converter, the silicon, carbon and phosphorus are entirely removed, and the metal is very nearly pure iron. If a small quantity of ferro-manganese or ferro-silicide is then added to partly reduce the oxygen, and the metal is cast into ingots and rolled, it will be found to possess a highly fibrous character, much superior to fibrous wrought iron made by the puddling process. And if sufficient ferro-manganese or ferro-silicide is added to thoroughly deoxidize the metal, when rolled it will be found to possess a fine crystalline texture. In both these cases the ingot iron so made will be very ductile. When ingot steel is desired, the metal, when desiliconized, decarbonized and dephosphorized, should be removed from the slag, and then deoxidized and recarbonized in the usual manner.

When an open hearth is furnished with a lime lining, and the metal is held at a high temperature in the presence of a highly basic bath, until the silicon and carbon are eliminated and the silicic acid is engaged as silicates, and carbonic oxide disappears, and the slag is still sufficiently basic, the phosphorus is rapidly eliminated and remains in the slag as a phosphate of iron, the metal may then be treated with ferro-manganese or spiegel, for deoxygenizing and recarbureting it.

In both the Bessemer and the open hearth practice it is desirable that the metal should be removed from the presence of the phosphoritic slag before the ferro-manganese or spiegel is added, as the chemical reactions which take place when these elements are added, tend to carry a portion of the phosphorus from the slag back into the metal.

The quantity of slag required will depend on its degree of basic purity and on the amount of silicon and phosphorus to be eliminated, the essential requirement being that the slag shall possess sufficient basic material to engage all the silicic acid as silicates, and all the phosphoric acid as phosphates. To secure these requirements in excess, the weight of the slag will range from 25 to 30 per cent. of the weight of the metal.

In the economy of the new basic dephosphorizing process, it is desirable to produce metal for this process containing as little silicon as practicable, so as to prevent the appearance of silicic acid in the slag so far as possible. And as the reduction of silicon is a reduction of the source of heat, it is desirable to increase the percentage of phosphorus in the metal in proportion to the heat units withdrawn by the reduction of silicon. Therefore the most desirable metal for the new basic dephosphorizing process is that which is low in silicon, and containing from 2 to 3 per cent. of phosphorus.

When metal containing 2 per cent. of phosphorus is treated in a lime-lined converter, and in the presence of 25 per cent. of a highly calcareous basic slag, the slag when withdrawn will be found to contain 18.32 per cent. of phosphoric acid to weight of slag, or 4.58 per cent. of weight of the metal.

In order to obtain a metal from any class of ores, suitable for the new basic dephosphorizing process, containing a minimum of 2 per cent. of phosphorus, and to economize the cost of the basic calcareous slag, it is proposed to use this calcareous phosphoritic slag as a flux in the blast furnace in place of so much limestone. When this slag containing 18.32 per cent. of phosphoric acid is used in a blast furnace in proportion to $\frac{1}{4}$ ton of slag to 1 ton of metal produced, the phosphate is reduced by the carbonic oxide and silicic acid to a phosphide, and the metal produced will contain 2 per cent. more phosphorus than was obtained from the ores from which the metal was smelted.

Thus the phosphorus which is utilized by oxidation for the development of caloric essential to keep the metal in a highly fluid condition in the basic converter, is again utilized by its reduction in the blast furnace, securing economy and an absolute control of the production of a minimum of 2 per cent. of phosphorus in the metal made from any class of iron ores; which is desirable, as it is more convenient and practicable to eliminate 2 per cent. of

phosphorus from the metal by the basic process than it is to dephosphorize a metal containing one-tenth of that amount of phosphorus and 2 per cent. of silicon.

The essential requirements of dephosphorization having been determined as set forth, *i. e.*, the oxidation of phosphorus in the presence of a highly basic slag and in the absence of free silicic acid and carbonic oxide, it is proposed to dephosphorize molten metal flowing from a blast furnace by treating it at a low temperature in the presence of a highly basic slag, and withdrawing the metal from the slag after it is dephosphorized and before the oxidation of the carbon takes place, and running the oxidized metal into pigs, or taking the metal and treating it in the acid Bessemer converter, or in an acid-lined open hearth.

It is also proposed to dephosphorize molten metal direct from the blast furnace as before described, then running it minus the slag into an open hearth, and there desiliconizing it down to .025, and then withdrawing the dephosphorized metal and running it into pigs. Such a metal would be low in phosphorus, high in carbon, and practically free from silicon, and would be a superior chilling iron for the production of chill rolls, car wheels, and most excellent for gun metal and malleable castings, and all foundry purposes.

It is also proposed to desiliconize and decarbonize metal in the acid Bessemer converter, and then run it minus the silicious slag into a basic-lined converter or open hearth, and there dephosphorize and refine it, and then run the metal minus the phosphoritic slag into a ladle and deoxygenize and recarbonize it in the usual manner, and cast it into ingots.

Having explained the distinguishing characteristics of the old processes and the essential requisites to dephosphorization possessed by the new basic process, I will now venture a few predictions as to "what we may expect from it."

The basic dephosphorizing process will eliminate all the silicon, carbon, manganese and phosphorus contained in the metal and produce nearly pure wrought iron.

As the fibrous character of wrought iron is caused by oxide of iron being interstratified in alternate laminæ with the iron, and as the molten metal in the basic converter will, at the end of the blow, be somewhat oxidized if a small quantity of ferro-manganese be added to it, but not in sufficient quantity to reduce all of the oxygen, the ingot iron produced by the basic dephosphorizing process when

rolled down will exhibit a highly fibrous texture and possess in a superior degree the properties of ductility, malleability and welding, which are possessed by the best Swedish or Norway iron;—therefore the importation of such irons will cease when the basic wrought iron is put upon the market, as the latter will be better and cheaper.

And as pig metal designed for the basic dephosphorizing process may be made from the cheapest class of ores, smelted in a blast furnace in which a hot blast of the highest volume and temperature is employed, the metal will be of the cheapest class produced; and as such metal, whether white, mottled or gray, can be put into fibrous wrought iron at less cost by the new basic dephosphorizing process than it is now, or can be, put into muck bars by the puddling process, we may expect that the history of the puddling process will be closed at an early day.

By incorporating with the basic metal just sufficient ferro-manganese to thoroughly deoxidize it, the ingot iron when rolled down will possess a fine crystalline texture, and yet be tough and ductile. Thus it is conceived that the fluid basic dephosphorizing process will not only produce a superior quality of steel containing any degree of carbon, chemically combined, from .00 to 2 per cent., but it will also produce wrought iron, both fibrous and crystalline, of a quality superior to any produced heretofore by any other process. And as the degree of expansion and contraction between any given temperatures will be increased in proportion to the amount of carbon contained in a metal, and as the fluid basic dephosphorizing process is capable of producing *ingot iron free from carbon*, we will be able to produce, by this process, a superior quality of wrought iron possessing all the essential characteristics required for *structural purposes.*

Believing, as I do, that graphitic carbon is held in the pores of the physical structure, and that the portion of carbon which is said to be chemically combined is held in the pores of the chemical structure, the most pure iron having its pores empty, when recarbonized will take up a greater amount of carbon and exhibit greater elasticity and resilience than less pure iron so carburized. Hence we may expect to produce, by the basic process, *spring steel of a superior quality.*

As the most pure iron will take up the largest amount of chemically combined carbon, or in other words will accommodate more carbon in the chemical pores, when such iron is highly carburized

the steel will be harder and the texture more dense; therefore we may expect to produce moldboards, landsides, plow points and other agricultural steels of superior quality, by the basic dephosphorizing process.

As pure iron is silver white, of a very agreeable, mild and at the same time brilliant lustre, steel produced from such iron will possess a finer texture and be capable of exhibiting a higher polish and a more beautiful lustre than iron or steel of less purity. Hence we may expect to produce steel for cutlery, cutting tools and other polished work of a superior quality, by the basic dephosphorizing process.

The new process will produce rails of ingot iron or of any degree of carburization desired, and I believe that rails containing .60 to .75 of carbon, made by the basic process, will be stronger, tougher, and wear double the tonnage of rails now made by the Bessemer acid process.

The basic process will produce better iron for *tin plate*, for *galvanizing*, for *stamping* and *drop forgings* than has ever been produced by any other process.

It is proposed to produce pure iron by the basic process and then re-carburize it by infusing plumbago into the metal, and thus avoid the reactions which take place in re-carburizing by the use of ferro-manganese or spiegel. Basic steel may be produced by this method possessing the peculiar characteristics of tool steel.

Pig metal for the basic process may be made from all kinds or qualities of iron ore, but for reasons before mentioned it is desirable that the metal produced shall be low in silicon, and contain not less than 2 per cent. of phosphorus. Hence by the utilization of phosphoritic ores, the centre of greatest production of iron and steel may adjust itself to the economy of the basic process.

In the economy of the basic process the blast furnaces and the converters, or the open hearths, will be located near each other, so as to save fuel and freight on the phosphoritic slag.

The metal produced by the basic process being in a fluid condition, it may be cast into ingots of any desirable shape; and as mechanical operations will be employed to work these forms in large masses, the old rolling mills may not prove economical.

As ingots designed for plates may be cast of any desired width, and as the ingots will be reduced to plates principally by automatic process of rolling, nail plates, tank and ship plates will be

produced at less cost than such are now produced by the old processes.

In conclusion, I believe that the fluid process, *i. e.*, the Bessemer and open hearth, with the basic dephosphorizing improvement, will in time supersede all others for the production of iron and steel, and will ultimately enable the United States to become the greatest exporter of iron and steel in the world.

DISCUSSION.

MR. JAS. PARK. *Mr. President:* I presume that most of the members of this association — the majority of them — are well aware, from the class of discussions that has taken place here, that I have been in the habit of speaking whenever I could, where I knew nothing of the subject. I rather like this, because I cannot be blamed when I speak if I am ignorant of the subject.

In reference to this paper I would say, that the author is as well qualified for writing it as any man of his day—that the paper is one worthy of the pen of any man, I do not care where he may spring from. But I always like to differ with people. It is born in me. I cannot help it. I would like to call Mr. Reese to account for some things that I do not consider sound in his paper.

I have always been, as you know, a very strong advocate of the proper use of the word *steel*, and I regret that some other word has not been adopted in our language for that metal. I am sorry to say that this disposition to rob that metal of its true name is not dying out. In the first part of the paper I was glad to hear the word ingot steel. I like that. No other word ought to be used when steel is referred to in that shape. I find that Mr. Reese uses the word ingot iron. He says in one place that "when ingot steel is desired, the metal," &c., (see p. 181, 2d paragraph). In this instance he is correct. I cannot criticise this. But I find him saying in several places here, "ingot *iron* thrown in"—"in both these cases the ingot *iron* will be very ductile." I find this repeated in a number of places.

Now, as I hold that metal made by fusion and cast, showing crystalline or granular texture and is malleable, (except what is known as malleable iron castings) is steel, and nothing but steel, I have to express regret that Mr. Reese made use of the word ***iron.***

I can readily understand why foreign people would use the word in this sense. But I am sorry Mr. Reese has used the term ingot ***iron.***

I want to refer to a little matter which I hope he can explain. (See p. 181, 4th paragraph). "In both the Bessemer and the open hearth practice." I do not know just how that can be done—how the metal can well be removed from the presence of the phosphoric slag before the ferro-manganese is added. I ask him to explain this, and then to beg pardon of this association for using the word *iron* instead of *steel.*

MR. REESE. In reply to the gentleman I would say, that in regard to the ingot iron I do not quite understand his position, and I think we have been working on these matters for some time.

In the basic dephosphorizing process we will be better able to produce iron free from carbon than by the Bessemer acid process. As you are well aware that in the Bessemer acid process, depending as it does on carbon and silicon for the caloric to keep the metal in a fluid condition, as the process approaches the end of the blow, these materials are so diminished that there is very little caloric developed at the end of the blow compared with that at the beginning.

The tendency is to lose caloric at the end of the blow, while in the basic dephosphorizing process we depend more on phosphorus for the development of heat; consequently the metal is more fluid than it is in the acid process, and by this means we are able to produce a metal more free from carbon. I have analyzed metal in which was found no trace of silicon, but a trace of phosphorus, and no trace of carbon.

I have seen a plate of this metal, of No. 20 gauge, which had been stamped into a bucket which was ten inches in diameter and twelve in height, with all the edges perfect. It was apparently as soft as copper.

We thus increase the ductility of iron when it is free from carbon, silicon and phosphorus.

MR. PARK. I do not know that it is necessary to have any carbon in the metal to have steel; because many of the most eminent authorities contend that any metal that is made by fusion, is crystalline and granular in structure and is malleable, (except what is known as malleable iron castings) is steel, without reference to its percentage of carbon.

MR. REESE. *Mr. President:* I made application to the Patent Office some years since for a patent for fibrous steel, and my application was rejected. I repeated the application, but had finally to

give it up, because at the Patent Office they got some eminent chemist to analyze my fibrous metal, and there was found no trace of carbon in it, no silicon and but little phosphorus. This was one of the finest fibrous metals I ever saw in my life. I failed to get a patent. I call the metal produced by the basic process, when it is free from carbon, ingot iron, because the government refuses to recognize iron as steel when the metal does not contain carbon, and because the technical societies of Europe and America have adopted the term ingot iron (German flusseisen, French fer fondu), to denote a metal made by a fluid process and which will not harden when, at a red heat, it is put into cold water. For these reasons I think that the term ingot iron is properly used when the metal does not contain carbon.

MR. PARK. We find, once or twice a year, a specimen of metal of long fibrous steel. Its appearance we cannot account for. It is a black sheep that comes in we know not how. We look on this as one of the bad things that come about our place. We do not like it. I am very glad the Patent Office has refused to give a patent to Mr. Reese for patent fibrous steel.

MR. REESE. Still, I do not see why I may not call it ingot iron.

In regard to phosphoritic slag, we draw the metal from the slag. One way of doing it is to run the metal out of the furnace through a shield that permits the metal to flow out while the shield prevents the slag from following it. Or, the whole charge may be run into a ladle, and the metal tapped from the bottom into the deoxygenating and recarbonizing vessel.

MR. CHARLES PARKIN. I am very glad the question of fibrous steel has been discussed. I have handled large quantities of Bessemer steel of low carbons, and have never seen any of it when rolled down to say 10 or 11 gauge, but that would roll into a fibrous condition.

When left in larger sections it would retain its crystalline structure.

I think the reason of it is the crystals are so large and coarse in low carbons that they are drawn or crushed over one another when rolled to thin gauges.

I question whether Mr. Reese, by his process, can produce fibrous steel of say 70 or 80 carbon.

MR. REESE. I think Mr. Parkin is correct in saying that fibre does not appear in high carbon steels. It does not appear in my paper. My fibrous ingot iron is free from carbon.

To determine the cause of fibre in iron, I took a $\frac{3}{4}$ in. bar of wrought iron and a $\frac{3}{4}$ in. bar of carbon steel, and put them into a glass tube, and subjected them to chlorine gas at a high temperature. The steel bar was decomposed entirely, but the fibrous wrought iron retained its form. I could only see that it had been operated on by the color of the escaping gases. When I concluded the experiment was done, I took the plate out on which it stood. But when I blew on it it went into thin ashes. Being analyzed it showed oxide of iron ninety-seven per cent.

Mr. Wm. Metcalf. I agree with Mr. Park as to his use of terms. The American Institute of Mining Engineers, in 1876, in discussing the report of the International Committee on Nomenclature, declared the following to be the correct *commercial nomenclature* of iron and steel, and merely recommended the use of the proposed nomenclature in papers to be written by members, for convenience in exchanges.

- Iron
  - Wrought
    - Bloom
      - Catalan.
      - Finery.
    - Puddled
      - Bars.
      - Plates.
      - Beams, &c.
    - Steel
      - Blister.
      - German.
      - Shear.
      - Puddled.
  - Cast
    - Not malleable
      - Pig iron.
      - All ordinary castings.
    - Malleable
      - Castings, annealed and decarbonized in oxides.
      - Steel
        - Castings not highly carbonized.
        - Crucible.
        - Bessemer, or pneumatic.
        - Open hearth
          - Or Siemens-Martin, and Siemens by pig and ore processes.

I dislike Mr. Reese's use of the term wrought iron as applied to material made by fusion and cast in ingots, because "wrought" is a good old word which conveys the idea of something which has been worked, and more or less manipulated by hand: and it is so distinctive that it ought to be kept for its present use, implying iron which has been hand-worked, rather than that which has been melted and handled almost exclusively by machinery. I think

fibrous steel is nothing more than steel which contains a good deal of oxide of iron, which causes thin sheets of this steel, usually very mild, to appear laminated and fibrous like wrought iron. I do not believe that all of the possibilities of Bessemer and open hearth steel have been developed, but they are much further away from the production of fine and reliable tool steel than Mr. Reese suggests. It is well known that mild cast steel is more ductile than the best wrought iron, as is well instanced in the case of a steel ship which ran fair on a rock at full speed. Instead of sinking, the ship made port, when it was found that the bow was staved in to an enormous extent, but not a plate was cracked nor a rivet started. No iron ship was ever built that would have endured such a blow and floated. All products of the crucible, Bessemer converter and open hearth are known to the trade as *cast-steel*, and this compound word so applied, is just as distinctive and as proper as any word we have in use, and need not be confused with the old-fashioned word steel, or any of its scientific definitions.

MR. REESE. I do not think we could make steel with the fibre, and have carbon there too. I do not see this referred to in the paper. In regard to the gases I think you are correct. In the open hearth process the metal is allowed to remain at rest. In the crucible process you also have an advantage in the use of plumbago. You have a different steel in your process from what it is when entirely recarbonized by ferro-manganese or spiegel. Now by the use of plumbago in the basic process we may produce different results; and until this is tried you cannot tell what the effect will be.

NOTE.—As the priority of invention relating to all the essential features requisite to the new basic dephosphorizing process is now in litigation in the cases known as "Reese vs. Thomas," until the priority of invention is determined it will not be known whether myself or Thomas and Gilchrist will control the new basic dephosphorizing process in the United States. For this reason I have given this paper a general character, and have carefully avoided reference to the claims of invention.

All matters in the case of "Reese vs. Thomas," have been decided in favor of Reese, after hearing of Thomas' final appeal before the Commissioner of Patents.

JULY 5TH, 1882.

NOTES OF A TRIP THROUGH THE JAMES RIVER VALLEY.

By Jos. D. Weeks, Associate Editor of the "Iron Age."

[Read February 22, 1881.]

In the social and political history of this country the Valley of the James plays no inconsiderable part. At the time of its first settlement, near the opening of the seventeenth century, the daring and adventures of one of the most remarkable men of modern times threw a glamour of romance about its waters and gave its banks a wealth of legend that even yet has all the charm of fiction and the interest of history. Nearly two centuries later the closing scenes of the American Revolution were enacted on its banks, and across its waters echoed the last gun of the war that gave this nation existence. And when, near the close of another century, the question whether that existence should be perpetuated was submitted to the arbitrament of war, this valley felt the heaviest shocks of battle and witnessed at Appomattox the decision of the contest.

Strangely enough, however, though the beginnings of our industrial life, as well as our political life, were on the banks of the James, its industrial history has been very meagre. As early as 1608, less than two years after Captain Newport brought his first vessel to anchor in its waters, the manufacture of glass was begun near Jamestown; and in 1619 or 1620 an iron works was established at Falling Creek, a branch of the James. It was also from Virginia, which at that time meant only the James River Valley, as early as 1609, that the first exports of manufactured articles from this country were sent to England.

The industrial life of which these beginnings gave such bright promise, has had no vigorous growth. Iron works have been established at various points in the State, but they have attained little or no prominence, except in certain cases for excellence of product, and

have led to the building of no large centres of iron industry such as exist in Pennsylvania.

This lack of industrial life in the valley of the James—of those conquests that mark this century—has not been for want of opportunity. For fifty years it has had developed, in the James River and Kanawha Canal, one of the grandest water powers on this continent; one, in comparison with which the Merrimac, which turns the busy spindles of Manchester, Nashua, Lowell and Lawrence, is an insignificant stream; and yet this power has lain fallow, while, shaken by the very rush and roar of its waters, forming the very sides and containing walls of the pools and reservoirs that store up this vast power, has been a wealth of undeveloped mineral resources with which few if any other States have been endowed.

It is more especially to some of the mineral resources of this valley that I wish to direct your attention.

Finding its source in the heart of the Alleghenies, the James runs parallel to their base in a southeasterly direction for some distance, breaking through their most easterly spur at the magnificent pass of Balcony Falls, and still pursuing its general southeasterly direction until it strikes Mount Athos, some six miles below Lynchburg, where it turns abruptly to the northeast, being deflected by the massive quartzites which carry the mountain. It runs in this general direction for some 50 miles, to Scottsville, where it resumes its southeasterly direction to Richmond.

In this valley "are found in great abundance and of superior quality, every variety of ore that is profitably worked for iron anywhere in the world, with the exception of the carbonates, like the 'clay ironstones' and 'black band ores' of England." * In the upper part of the valley, before the river breaks through the Alleghenies, especially at Clifton Forge, at the point that has been so felicitously called "Iron Gate," and at various other points, are found deposits of brown and red hematites that can only be described as immense. At points in this region huge cliffs of ore form the summits and sides of spurs and hills, while along their sides and at their bases are scattered lumps and boulders of solid ore of a fair quality and in sufficient quantity to supply the furnaces of a city like Pittsburgh for months.

Between Balcony Falls and Lynchburg other immense deposits are said to exist; but of these I can speak only from hearsay.

* Prof. Campbell.

Below Lynchburg, however, at the very point at which the James turns toward the north—is not this significant?—begins a remarkable ore region. Veins of rich and pure slate and magnetic ore run parallel to and at no great distance from large veins of red and brown hematites, not so rich or pure as the former, but sufficiently so to make very good forge irons.

For the entire valley, from Mt. Athos to Scottsville, or from the point where the James turns to the north to where it resumes its southward direction again, the ore-bearing rocks have been traced. The northwestern boundary of these rocks is the Buffalo Ridge and its extensions. The southeasterly has not been determined. Sufficient has been learned, however, to indicate that the rocks have a width of several miles and that they extend through the State in a southwesterly direction. Extensive openings have been made on the Mt. Athos property, which extends some six and a half miles down this valley, which have developed as many as sixteen veins of ore. The ore-bearing formations consist of alternations of quartzites and micaceous, talcose and chloritic slates, having a dip of from 10° to 45°; usually, however, nearly vertical.

The ores of the Mount Athos property have been divided into four systems or belts:

(1) Mount Athos.
(2) Chestnut Mountain.
(3) The Red Ore.
(4) The Pot Ore.

To a Pittsburgh audience the most important of these belts are the first and second. The ores in these belts are mostly specular and magnetic, with one vein of manganiferous. What is locally known as No. 7 of the Chestnut Mountain system is a fine high grade micaceous ore. Two shafts have been sunk on this vein to a depth of 90 feet and connected at the bottom. These shafts show the ore to be 12 feet wide, one-third of which will yield 65 per cent. of metallic iron, and the balance 40 per cent. to 55 per cent., all free from sulphur and low in phosphorus.

No. 14 of the third or red ore belt consists of a series of red and brown hematites, alternating with slate, of a total breadth of from 300 to 600 feet, the ore veins being from 2 to 20 feet. The red hematites of this belt are low in phosphorus and free from sulphur carrying from 40 per cent. to 60 per cent. of metallic iron.

It is not possible in the limits of this paper to enter into a detailed description of these deposits. The investigations show that there exists an immense body of easily mined ores, many of which are low in phosphorus and high in metallic iron, some of the best carrying considerable manganese. The chief drawback is the smallness of the rich veins and the necessity of the careful selection of the rich ores from the gangue of the leaner, but experience seems to prove that the veins not only grow wider as they descend, but, in the case of the low grade surface ores, richer. The following analyses are of the different veins of the Mount Athos property:

ANALYSES.

	VEINS.		
	No. 1.	No. 3.	No. 7.
Silicic acid (quartz)	3.04	14.67	4.10
Titanic acid	0.10	0.12	0.15
Phosphoric acid	0.11	0.08	0.02
Ferric oxide	91.39	82.38	90.74
Manganic oxide	0.17	0.32	0.11
Alumina	4.20	1.96	4.43
Magnesia	0.15	0.06	0.12
Lime	0.20	0 23	0.29
Water	0.64	0.18	0.04
	100.00	100.00	100.00
Metallic iron	63.97	57.68	67.71
Phosphorus	0.048	0.035	0.009

	No. 1.	No. 4.	No. 10.	No. 13.	No. 15.	No. 16.
Metallic iron	56.667	36.16	60.18	53.50	57.70	56.38

Note.—Nos. 1, 4, 10 and 15 are almost free of phosphorus.

SUNDRY ANALYSES OF No. 14.

Metallic iron	41.52	33.59	48.33	30.88	56.80	50.632	68.062
Phosphorus	0.265	0.079	0.47	none	0.97	1.836	0.008

	No. 1.	No. 3.	No. 4.	No. 4.	No. 4.	No. 10	No. 13	No. 16
Metallic iron	65.713	62.987	57.600	64.85	33.43	62.126	42.02	39.357
Phosphorus	0.046	0.172	0.048	tr'ce	0.12	0.159	1.01	0.110
Sulphur	none	0.022	none			0.011		0.032

SUNDRY ANALYSES OF No. 7.

Metallic iron	72.760	67.05	67.797	68.340
Phosphorus	0.015	0.01	0.019	0.008
Sulphur	0.031		none	trace

Note.—Vein not numbered. Available binoxide of manganese, 67.20.

At a short distance below the Mt. Athos property these same ores are being mined quite extensively. Dr. J. P. Kimball, in reporting on these deposits, says: "The ores are disposed in beds or veins between strata of different composition. They seem to me to be, unlike the ferriferous schists of Michigan and Missouri, segregated deposits of ore which have been metamorphosed along with the whole series of strata. The degree of metamorphism has been slight as compared with the Hurorian schists, and in some cases they are still soft or only partially altered. While specular hematite is the prevailing form of iron ore, some of the deposits are in part in the state of magnetic oxide; others again are admixtures of magnetic and specular oxides; while still others, especially those of which limestone forms one of the walls, are compact brown hematite (limonite)—at least near the surface."

It is not necessary to enter into the details of the formations at these points, as they are similar to those at Mt. Athos. As showing the character of these ores, however, we append a table of analyses:

Greenway Mine.	Greenway Mine, Vein 16.				Harris Tract, 3-5 feet on foot wall.			Hematite, Payne Tract.	Magnetite, Payne Tract.	Specular, Coxe Tract.
								No. 1.	No. 3.	—
Metallic iron	66.32	66.622	64.84	65.80	65.158	61.12	60 62	53.01	69.71	62.63
Phosphorus	0.035	0.022	0.049	0.025	0.025	0.088	0.013	0.135	0.25	0.06
Ferric oxide	95.24	92.002	....	....	....	....	....	....	....	....
Manganous oxide	0 9	....	....	....	....	....	....	....	....	....
Alumina	0.53	1.839	....	....	....	....	....	....	....	....
Lime	0 4	....	....	....	....	....	....	....	....	....
Magnesia	0.7	....	....	....	....	....	....	....	....	....
Silica	3.29	3 96	6.07	6.36	....	7.68	8.87	11.26	7.87	11.54
Phosphoric acid	0 8	0 052	....	....	....	....	....	....	....	....
Sulphur	....	0.177	....	....	....	....	....	....	....	....
Titanic acid	trace	....	....	....	....	....	....	....	....	....
Water	0.66	....	....	....	....	....	....	....	....	....

Riverville and Wingfield.	Bed VI½.	Bed III, Riverville.	Bed V, Riverville.	Bed VI, Riverville.	Bed X½, Wingfield.	Bed XI.
Metallic iron	66.229	65.71	57.68	65.71	52.98	57.30
Phosphorus	0.023	0.009	0.035	0.046	0.23	0.30
Ferric oxide	94.613	90.74	82.38	91.39	75.69	81.86
Manganous oxide	none	0.11*	0.32*	0.17*	0.29	0.20
Alumina	none	4.43	1.96	4.20	3.76	3.06
Lime	trace	0.29	0.23	0.20	1.29	1.38
Magnesia	.....	0.12	0.6	0.15	0.25	0.18
Silica	4.370	4.10	14.67	3.4	16.60	11.32
Phosphoric acid	0.052	0.2	0.08	0.11	0.54	0.70
Sulphur	none	.....	.....	.....	.....	.....
Titanic acid	.....	0.15	.....	0.10	0.18	0.22
Water	.....	0.4	0.12	0.64	1.40	1.08

* Ferrous oxide.

Stapleton.	Cherry Tree.	Six ft. vein.	Stapleton Cliff.	Lee Red
Metallic iron	54.65	46.09	47.20	56.00
Phosphorus	0.29	0.10	0.32	0.06

Stapleton.	Kent.	Maude.	Tinsley. Manganiferous (34.56 Mn.)	Maude. Aver. shipments Jan. to March.
Metallic iron	59.92	62.796	22.57	63.43
Phosphorus	0.001	0.099	0.08	0.06
Manganous oxide	.....	.....	54.669	.....

The ores of the James River Valley, above Lynchburg, are, as a rule, hematites, with a somewhat higher percentage of phosphorus, and lower in metallic iron than the specular and magnetites of the Mount Athos region, but existing in much larger deposits and more easily and cheaply mined. Prof. Campbell, of the Virginia Military University, in a report made by him to the James River and Kanawha Canal Co., speaking of this part of the James River Valley, says: "The canal and its railway connection traverse every one of the five great ore-bearing geological formations of

Virginia, and one of the finest limestone regions of America." Of the developments in the neighborhood of Clifton Forge and Iron Gate, Prof. Campbell writes: "'Red-shale' and 'Fossil' ores are mined at Clifton Forge, where they are found in the shales interstratified with the heavy beds of hard gray sandstones that constitute a large portion of the remarkable arches, or rather succession of concentric arches, so strikingly displayed where the river passes through Rich Patch Mountain. The ores of this formation were extensively mined on the eastern slope of Rich Patch Mountain for some years, to supply the Roaring Run Furnace in Botetourt county. They are now highly valued for mixing with the more silicious ores of a higher formation, those of No. 7, of Rogers, and, when their real value becomes better known, I have no doubt that they will be developed in many new localities along the faces and flanks of both North and Rich Patch Mountains.

"Analyses of seven samples, from different localities, give a range in percentages of iron from 38.71 to 57.12, and an average of 49.45; a range of phosphorus from 0.14 to 0.98, and an average of 0.38 for four samples.

"The ridges that have been thrust up from the bottom of our great trough-like valley are very important features; for they have lifted up and brought to view extensive beds of both ore and limestone for the use of furnaces; as, for example, at Longdale and California furnaces, both supplied from the same uplift, Brushy Ridge.

"To illustrate the resources of this formation, it is only necessary to enumerate the principal furnaces that are now, or have been, supplied from its beds of ore. Beginning at the Augusta end, we have in that county, Buffalo Gap, Ferrol (Elizabeth), and Esteline furnaces; Bath and California, in Rockbridge; Australia and Longdale, in Alleghany; and Rebecca, Callie, Roaring Run and Grace, in Botetourt.

"Longdale and Callie furnaces have very large and still widening developments of very fine ores; and they are both within reach of competition in transportation. Then along the base of Rich Patch Mountain on the Kayser lands, and at points south of Callie Furnace, as on the lands of Messrs. Woods and Reynolds, there are promising indications of ore beds not yet opened to any great extent. This belt of undeveloped beds extends along the western and middle

portions of Craig county for some miles beyond Newcastle. The on the western slope of North Mountain, the still inexhausted beds of the old Rebecca Furnace, near Dibrell's Springs, are only awaiting transportation and cheap fuel.

"Let us now tabulate all these general results of the analyses of the ores of the four belts west of the Blue Ridge:

Formations.	Range of metallic iron.	Range of phosphorus.	Average of iron.	Aver. of phosphorus.
Primal, No. 1	40.62 to 55.84	0.06 to 1.08	50.87	0.35
Hudson, No. 3	48.97 to 55.66	.....	51.91	.....
Clinton, No. 5	38.71 to 57.12	0.14 to 0.98	49.45	0.38
Oriskany	36.25 to 58.29	0.03 to 0.96	51.12	0.38

A letter from the owners of Callie Furnace, near Clifton Forge, speaking of their magnificent deposits of ore, says: "I would have liked very much to have shown you two of our openings you did not see—one a very fine ore of very dark color, manganese ore, a new opening, just made, very rich in iron. The other our new red ore, which has been tested by the Cambria Iron Company, who report .0189 of phosphorus and 54 per cent. of iron, and this from the surface, before being opened, as it now is, showing 25 feet in width, and not through it yet."

Of the Reynolds Bluff, before mentioned, which now belongs to Mr. D. S. Cook, and is called the Walton Mines, the vein of which is at least forty feet thick, Mr. Cook gives the following analysis by Mr. Britton:

Metallic iron	51.57
Silica	13.46
Sulphur	none
Phosphorus	0.049

This was a surface specimen. Another surface specimen gives:

Metallic iron	59.410
Sulphur	none
Phosphorus	0.289

"The phosphorus would be probably less, further in the vein."

We have not mentioned these properties in detail because they were more promising than a score of others in this valley, but

because we have more definite information from them. We have used them only as types of what seems, all things considered, to be one of the most interesting and important ore sections in the country —a section where there is as much activity at the present moment in ore as in any part of the country. Our most prominent and sagacious ironmasters are investing largely in these lands, and at their suggestions capitalists are joining them. New furnaces are constructing and old ones are repairing and going into blast. Ferrol, Callie, Low Moor, Longdale—all modern coke furnaces—are or will soon be in blast in the neighborhood of Clifton Forge, and making iron at a cost of not more than $12 a ton, and in some cases less than this.

And what of all this to Pittsburgh? We are a society of engineers, who are popularly supposed not to be influenced by the "*Cui bono*" of the practical man; but after all, this is the question: How is this to benefit Pittsburgh and Western Pennsylvania?

If Pittsburgh is to continue to manufacture and not to buy its pig iron, and the wonderful achievements of our furnaces and the improvements in progress warrant the belief that she will so continue, one of the most important questions in connection with the future of our furnace industry is the supply of ore.

Of the value and abundance of the rich and pure ores of Lake Superior and Missouri there is no question, and the fact that for years to come we must draw a large percentage of our supplies from this locality is also evident; but it is only the dictate of a wise business policy to secure, if possible, other and nearer sources of supply. The locality in which these supplies are to be sought is undoubtedly the Virginias. They are the nearest, and the indications are that they are the purest and most abundant. Within less than 300 miles of this city, "as the crow flies," lie these immense bodies of ore, of some of which I have tried to give you some general idea. That they can be mined cheaply, and are suitable for our furnaces and our work is proven by the facts. From the region below Lynchburg 60,000 tons have already been sold by Messrs. Naylor & Co. for delivery this year, mainly to Western Pennsylvania furnaces, among which are Dunbar, Charlotte, Edgar Thomson and Cambria. From the Low Moor property, for several years ores have been sent to the Ohio and down the river to Ironton furnaces. The product of Longdale and Quinnimont furnaces is well known in this market, and that of Callie and Low Moor will soon be.

The chief hindrance to the development of these ores has been the lack of transportation facilities. With the completion of the Richmond and Allegheny railroad, which is being laid on the tow path of the James River Canal, access to many of these ores will be easy; and as the grades are very low, freight can be easily moved; but the great hope is the building of a line of road to connect Pittsburgh through West Virginia with the Valley of the James.

The value of such a road to Pittsburgh cannot be told. In addition to opening up these vast stores of iron ore, it would open up a large market for our product that is now controlled by the East. The development of the South in the next ten years promises to be marvelous. Its rich and fertile lands are being broken up into small farms, and with prosperity will come a demand for all of the products for which our city is noted. Such a road would give us a new outlet to the sea, and that by a port that promises, if improvements in contemplation are carried out, to be the great seaport of the country south of New York.

I submit that here is a field for Pittsburgh's energy. Surveys are now in progress for this road, and I believe that if Pittsburgh will show an interest in the project in any way commensurate with the value it will be to her industries, the road will be built, the vast mineral resources of the James River region and the timber of West Virginia made cheaply available, and the great Southern market opened to her merchants and manufacturers.

DISCUSSION.

MR. WM. KENT. This question is one of vital importance to engineers and Pittsburgh at large. Some of the ores from this country are as fine as any I ever saw. In regard to the testimony and analyses made, I think they ought to convince the people that there is excellent ore there in very large quantities. There is something peculiar about the development of much of this Southern country. North Carolina, Virginia, Florida and other States were settled before Pennsylvania, and although some of them possess natural valuable resources equal to Pennsylvania, they have lain dormant. Virginia is now emerging from her stupor. Pittsburgh now has the opportunity to develop these immense fields of ore.

MR. REUBEN MILLER. I regret very much that I was unable to be present so as to hear the first part of this interesting paper, and on that account I feel that I hardly have a right to say that I would like to have this discussion postponed for two or three weeks.

Mr. Jos. D. Weeks. We have talked every year about the scarcity of ore and the high prices, and sworn that we would "never, no never," pay these prices again; and yet every time we have done it over again, when we have within 300 miles this enormous supply of iron ore. I believe the great trouble has been the lack of transportation. If Pittsburgh will just show it wants this road, it can have it. I do not think they want much money. If we make these men who are developing this region believe we want the road, that is all they want. Such a road would tap every great trunk line east of Chicago. I want to see a road from Pittsburgh through West Virginia and Virginia, more especially for the ores of Virginia. If Pittsburgh is to retain her prestige she must seize every facility.

Mr. W. F. Zimmerman. In conversation recently with an engineer familiar with the region described, he spoke of the vast quantities of ore, and said, as was mentioned in the paper, that Richmond would be before many years the largest seaport south of New York. I think the matter should be postponed and continued for discussion.

Mr. Reuben Miller. If the discussion were postponed it would be of course until the next meeting. I would suggest that after the paper is printed, copies be sent to the manufacturers and all interested, and that they be invited to be present and join in the discussion. Too much cannot be said on this subject.

Mr. Samuel M. Wickersham. Is it the railroad we are to consider or the ores? If it is simply a matter of the ores, they can be delivered now in any quantity. If we can have ore delivered for $8.50 per ton, I do not see any good of going to the expense of another road. And if we had a new road the probability is prices would be just as high. So far as the ore is concerned it rests entirely upon how low it can be offered. In this city we have plenty of low ore, and we are learning to manufacture these ores and make iron as cheaply as from the high ores. I do not think there is any question but that Pittsburgh will maintain her position. Years ago I heard this same cry that Pittsburgh was going to lose her place as a great iron centre, but in every case where trouble has arisen we have successfully met the difficulties, and Pittsburgh is to-day stronger than ever. The ingenuity of Pittsburgh manufacturers will always meet the emergency. I have seen cold blast charcoal iron lying on our wharves for over two years, offered at $14 per ton, without buyers. There is no doubt that Pittsburgh will continue to be the great iron centre.

MR. JOS. D. WEEKS. If there is any man who believes in the future of Pittsburgh I am that man, and this is the reason that I want to see a road put through. We want that Pittsburgh should have every facility. With regard to lowering the prices of ores and freight there is no use discussing the matter, it must be done if Pittsburgh is to maintain her position.

MR. T. P. ROBERTS. I think I could add a few words on the transportation question. I have been absent from Pittsburgh for some seven or eight months in the eastern part of the State. While in Chambersburg I heard a great deal of this ore, and also of the extension of railroads. It was proposed to strike into this country. Lately a New York company purchased titles to about 800 miles of railroad property in the South. The Atlantic and Mississippi, or it may be the A., O. & M., is pushing its lines. That is an index that some of the great capitalists see a great deal in this Southern country. I think that Pittsburgh ought to have the most direct facilities and the shortest lines to the South that can be had.

MR. WM. KENT. Two or three years ago the price of ore was $7 per ton at Cleveland, and I think it is about time some other places were receiving the benefits as well.

THE PRESIDENT. I started once to go through that country myself, but was unable to make the round trip. We spent a week in the Cranberry region and traced a vein for 28 miles without a break, openings not less than 5 feet in any case. The whole country is filled with fine forests. That country can also be reached as soon as Pittsburgh gets a Southern connection. We had some samples of ore from South Carolina; some of this we melted in a crucible, getting 28 lbs. yield, about 66 per cent. of the ore put in. We took some of this free from dross and melted it again with manganese and drew it into a bar, which was sent to one of our most expert axe makers, who sent back the steel made up into axes, and when asked said the steel was about as good as the Crescent brand, thinking we were trying to sell him some new material. And this was the result of a few crude tests.

MR. REUBEN MILLER. No section of the country is richer in pure fuel, nor has any portion more advantages, and if we have a fair chance we can hold our own and maintain our well-earned reputation; but when (as an expert has said) we permit ourselves to waste (by the use of antiquated appliances) an immense amount of this fine fuel, we must expect to find those who are wiser and more advanced catch up and endeavor to take from us our name and place.

This, however, is a digression, and may be the subject of future discussion. The necessity for this evening's discussion is presented in the fact that we must have another source from which to bring a portion of our supply of fine ore. We must not permit ourselves to remain in the position of manufacturers quarreling for the privilege of purchasing the supplies which are so necessary to our existence, but must so arrange it that there will be the same desire to sell to us that we continually exercise to sell to others. To supply this want the ore fields of Virginia are brought to our notice.

In the prosecution of this matter it will be best for us to take into consideration the cost of material used and the practice of the most favored nations, and to make up our minds that we must approach to this after making due and proper allowance for the desired difference in the wages of labor. A few words concerning fuel. We have near to us one of the finest deposits of coking coal in the world. It furnishes the following analysis: Carbon, 89.52; ash, 10.48; phosphorus, .018; sulphur, .859; as against this we have quoted the finest coke in England—the Durham, with which the best pig is smelted, and this shows: Carbon, 93.38; ash, 5.00; sulphur, 0.70; loss and moisture, 0.92. A difference against us of a small amount, and which analyses of other samples taken from the same mines may cause to disappear. The average cost of transporting this coke to the furnaces in Cumberland is $1.80 per net ton of coke. The cost of transporting coke from Connellsville to Pittsburgh is $1.16 per net ton, leaving at this rate a small balance in our favor. The ore which we require at present is from Lake Superior, and at current prices costs us $10 in Cleveland, to which add $2 transportation, making a cost of $12 at Pittsburgh. The cost of Cumberland ore, say at 12s. at the mine, or $2.91, and an average transportation cost of $1.10, makes a cost at furnace of say $4 against $12 for ours. Here now comes in an immense difference which we must overcome in some way. I say must, Mr. President, because it is proper for us to make up our minds to meet this difficulty and put ourselves in the position of the most favored people. This difficulty can be overcome only in one of two methods, by reducing the present cost of ore and fuel at the mines or by reducing the cost of transportation between the mines and the furnaces, or possibly both.

Let us take into consideration the cost of Lake Superior ore. I think we can assume that this ore, or one of similar quality, must be

laid down in Pittsburgh at not exceeding seven dollars per ton. My own impression is that we should say six dollars, inasmuch as it has been delivered in Pittsburgh for six dollars.

This may be done by increasing the supply of ore so that the possible supply can be in excess of the demand; and this excess in supply over demand can be effected by developing new territory and disproving the position now assumed by some, that all of the available good ore supply lies in the Northwest. However, before going into this in detail, let us see if there is not something which may be done to lessen cost of transportation; and in doing this I invite no tirade against our railroad friends, but hope in time that they may see it to their interest, as well as ours, to correct, if possible, these apparent evils.

To transport coke to this city we are required to pay a uniform tax of 2 cents per ton per mile, while from this city to Chicago the rate on the same material is only about ¾c. per ton per mile. Or, to give it in tons, say $1.16 per ton to Pittsburgh, and $3.50 per ton from Pittsburgh to Chicago, and $3.70 per ton from Pittsburgh to St. Louis. This, moreover, is the *open rate.* To transport ore from Cleveland to Pittsburgh we pay $2 per ton for 150 miles, although rumor says it is being passed through Pittsburgh at a lower figure. Now how does this affect us? In Chicago, ore which costs us $12 can be laid down for $8; and allowing 1½ tons of ore and 1¼ tons of coke to the ton of pig, Chicago gets for less than $20 what costs us over $21. We must try and convince our railroad friends that there must be a change in the direction of cheaper freights. At the same time we may be compelled to arrange for continuous rail delivery for a portion, at least, of our supply of fine ore, and not permit the supply of such necessary product to be entirely dependent on Jack Frost.

In the last report of the Pennsylvania railroad, I find the average earnings of the Pennsylvania railroad and branches shows .88 cent per ton per mile for all classes of freight. That on the Pittsburgh and Erie is much lower; but let us take this, which has allowed full payment of all fixed charges and plenty left after payment of a good dividend for a sinking fund. Ore, which is loaded by shipper, unloaded by consignee, which can be carried on the cheapest kind of cars, is not liable to depreciation from wet, nor can it well be stolen en route, should be carried at a profit of ¾c. per gross ton per mile (Germany less than ½c.).

The transportation of Lake Superior ore by continuous rail

service should enable shippers to put down ore in this city at $9.50, allowing $2.50 per ton f. o. b., but this is entirely too high a price.

Next let us turn our eyes towards the splendid deposits of Missouri and see what may be done there. Allow the same price f. o. b., and with transportation for 700 miles at ¾c. per ton per mile, we have a cost of $7.75 per ton of ore in Pittsburgh; and I have been told within a few days by persons indirectly connected with a railroad (not the P. R. R.), that an effort will be made to do this work at a less price than this. Here, then, is a closer approximation to our proved figures. However, let us take a look at what is done in foreign ore, for our instruction only, inasmuch as none of us wish to use foreign material when we have so much at home. In a late English publication we find that a company has now been formed which will deliver the fine Spanish ore at the furnace in Belgium at between twenty francs and twenty shillings per ton, and this after making proper allowances for royalty and transportation between mines and seaboard.

This price f. o. b. is given as 5.75 francs and is a lower price than I have known of late; although in June, 1879, during which year over a million tons were exported, the price stood at 5s. 6d. per ton, and in the same year advanced to 12s. 9d. Take, however, the estimate of 10s. per ton f. o. b., and 15s. for transportation, and this fine ore can be laid down at the seaboard at $6.07, or duty paid $7.25, and transported here to cost a little under $10. This price, although better than present Michigan prices, will not do for us to rely upon.

It may not be out of place, in this connection, to call to mind the cost of light charges for transfer and other service, which to some appear trivial, but which by being corrected or avoided may almost make a loss or a profit in ordinary times to a furnace proprietor. For instance, a transfer charge of 15 cents per ton costs, in ore, fuel and limestone alone, over 50 cents on the ton of pig, and this amount would in some years be accepted as an approved profit by the owners.

We must therefore, in all our efforts, endeavor to select a location which will bring us in direct communication with the ore banks and the coal mines, and avoid all transfers, bridge charges or tolls, under whatever guise they may be presented.

Another feature in the transportation question is to be considered. In ordinary seasons our railroad friends tell us that there

is an excess in eastbound over westbound freights, and would be glad to haul westbound freights such as ore, at cost a very small profit.

This fact should encourage us to work towards the seaboard source of supply, and it would seem to point either in the dire of Baltimore or the James river, either to Eastern Pennsylv and Maryland or to Virginia.

Mr. Weeks in his paper presents to us an account of some o most valuable deposits of fine ore, and which can be reached Pittsburgh by a road of say 300 miles. The developments of tract may not be as full as we would like, nor may the extent o deposits be as well defined as is necessary for the cold calculat of capitalists; but with such a prospect it is certainly well w while for us to extend the field of our examinations and make what is now shown to be probable.

This part of the discussion I will leave for those now pre with us to-night, and who are well fitted to teach us what is pr for us to do. However, before closing let us see what effe supply of ore from a deposit 300 miles away, and a supply of furnished at proper transportation charge would have on the iron industry.

As stated, the ore and coke used in a ton of pig iron now $21.32; but with ore at $2.50 f. o. b., transportation 300 miles per ton per mile, $2.25=$4.75 at Pittsburgh; coke at mine $ transportation, 1c. per ton per mile, 60c.=$1.85 at Pittsburgh: it takes two tons of ore and one and one-half tons of coke per t pig, and we have a cost for ore and coke of $12.27, as ag $21.32, or a difference of nine dollars in our favor in the man ture of the finest pig. Or let us take what can be done in Mid ore when the condition of the market is in favor of the buyers

Ore at mines	$2.5
Transportation from mines to lake	1.2
" by lake	1.7
" Cleveland to Pittsburgh	1.5
In Pittsburgh	7.0

This will put ore and fuel used in a ton of pig and now c $21.32 at $12.81, coke $1.25 at mines, presuming that we ha coke transported at 1 cent per ton per mile; but even this is

good for our Pittsburgh furnace as a supply from mines 300 miles away, transported by all rail and with an hypothetical disadvantage of a grade not fully up to the finest Michigan ores.

Mr. President, are not these things worth the time and money which should be expended in making the necessary tests and examinations? If so, we should lose no time in applying all our energies to the development of these new fields, and nothing but this will produce the result which must be effected if Pittsburgh is to retain her present proud position and maintain her title as the Iron City.

THE PRESIDENT. We have present a number of our leading manufacturers. I ask Mr. B. F. Jones to give his views.

MR. B. F. JONES. I do not know why I am called upon. I did not come here to speak. It is highly essential that we should have cheaper ores in this city. I think they will be obtained from some region like the valley of the James. I have no doubt that is one source from which we are to receive large amounts of cheaper ores. I think the manufacturers here ought to do all they can to develop the ores there. Considerable money has been spent and much has been done to show the quantity and quality of these ores, and the results have gone far in demonstrating their value. One of the first things to be done is to get a road down there. The local traffic alone would be sufficient to maintain the road. I think the increase and appreciation in value of land by reason of building the road would pay for half a dozen railroads. I came here to learn and not to teach others.

THE PRESIDENT. A number of gentlemen interested in this southern region are present. I call upon Mr. White, Attorney General of West Virginia.

ATTORNEY GENERAL WHITE. I came here to hear, thinking I might hear something to carry back to the people of West Virginia, encouraging to their hopes of building a railroad from the city of Pittsburgh into and through the State of West Virginia. In the valley of the James minerals may be found in large quantities and of valuable quality. I know but little about ores or their analyses, but judging from reliable proofs the ores there are equal or superior to the ores of Wisconsin. I have been assisting United States Senator H. G. Davis, of West Virginia, his son-in-law, and other gentlemen, in preparing a charter for a new railroad company looking for its northern terminus to this city. The idea of the projectors

of this road is to run a railroad from the city of Pittsburgh connecting with the Richmond and Allegheny R. R. at Clifton Forge, thus making connection with the whole southern country. The gentlemen at the back of this project are not mere scheming men. Senator Davis and his son-in-law are business men and men of capital. They have authorized me to say that they mean business in this matter. All that I can say is, that if any road is built in the direction of the James river and Richmond it will cross a country full of valuable minerals in coal and iron. There is nowhere such a timber country. There is a large extent of level country, said to be rich in virgin soil, and as fine timber as is known in this entire country growing from that soil. Some of this country is almost totally uninhabited, lying in the mountains away from everybody. It lies there to be developed and made a garden spot, and underlying that soil are abundant supplies of ores, principally iron and coal. Our people look to Pittsburgh as a city that will greatly prosper by developing their State. The people of West Virginia will extend to you every inducement to make it, as they believe it capable of being made, one of the greatest States in this Union. It has been said that the people of West Virginia are opposed to railroads; but you will find when you go down into that country that they will extend their hands to you and will give you every opportunity in their power. As an indication, the charter of the company, a copy of which I hold in my hand, is one of the most liberal charters ever passed by a legislative body. I believe Mr. Weeks, a member of your organization, has seen a copy of that charter. It not only allows but it invites them to build; moreover, they can mine as a railroad company, buy and condemn land and extend lateral branches; offering every inducement to push forward the development of the State, and thus throw into your city untold wealth. West Virginia invites you into this field and promises a large return if you will only come and help us.

MR. HOPKINS. I had no idea I was going to be drafted into the service, and would not presume to instruct this audience of practical men. I had the pleasure of accompanying Mr. Weeks, last November, and with him and all of the party was amazed at the universal resources of that undeveloped State. I had heard of the iron resources of the Virginias, and seen something of them in a former trip. I know nothing about the value of these ores, but I do know that there are immense deposits, one I saw extending for 15 miles

or over, abounding in iron. I appreciate the vast importance to Pittsburgh of having connection with these supplies of ore. We must reach out for cheaper ores in order to compete with other points.

I know that a great deal of prejudice exists against narrow gauge railroads, but the fact is there are ten thousand miles of narrow gauge roads in the United States; and for mountainous country they are the best adapted. I would say that the narrow gauge system is preferable because built and operated so much cheaper. When you remember that it costs but one-quarter as much, you can realize the advantage they would have in improving and developing a country. I would like to impress upon the manufacturers of Pittsburgh the importance of getting into Virginia. As a Pittsburgh man I feel anxious to see improvements going on. Not only are there vast quantities of iron and lumber but other mineral resources, such as zinc, copper and lead, and there are no great grades; so there are good reasons for Pittsburgh taking some interest in extending railroads south. In addition to that it would be to our interest in opening up new markets for our manufacturers. I do not think that many of us have any idea of that part of West Virginia except as a waste of country taken from old Virginia. It bids fair to be one of the wealthiest States in the Union.

Mr. Hart. Being largely interested in the iron ores of West Virginia, I came here looking for a market. I will state the little I know in as brief a space as possible. There are 20 or 30 mines on the James river, near Lynchburg; in that belt there are several veins of ore, numbered from 1 to 24. They are driving tunnels in the hope of cutting all these veins. We have sold Pittsburgh 60,000 tons of ore, which we hope to deliver this year—60 to 65 per cent. of the ore is metallic iron. Five dollars of the transportation go to canals and the rest are railroad rates. If you can furnish us a road of 300 miles from these mines to Pittsburgh you can reduce that $5.00 part to $2.50, and you can make your own calculation. I ought to say, in the matter of education, that I have been getting a little of mine this last year in learning that there is quite a difference between buying and developing an iron mine. [Laughter.] Whether it pays us to sell iron at $2.50 is a question I cannot absolutely demonstrate, but I think that when our plans are completed and steps taken, we shall be able to show that we can sell iron at that price. All the information I have been gathering is

that the deposits of ore contain many veins rich in iron and low in phosphorus, some pockety in character. Some of the lower grades can be mined pretty cheaply; that of from 50 to 55 per cent. of iron and from 5 to 10 per cent. phosphorus could be laid down here at $7 per ton. The transportation from Lynchburg is 450 miles, and we have at present a transportation rate of $3.50, so you can judge from that what the rate would be with a line of 300 miles. Mr. Miller spoke of making us tributary to Pittsburgh; what we want is to get other points tributary to us. If you give us a line 300 miles long we will endeavor to compete with anything else.

MR. REUBEN MILLER. The gentleman has hardly done justice to his field. I have here a pamphlet showing wonderful results as to metallic iron and phosphorus; the highest, .08 of one per cent. phosphorus, and from 40 to 67 per cent. metallic iron. The only thing to be ascertained is as to the quantity, and whether it could be mined. If the quality is as shown, and in any considerable quantity, the question is proved.

MR. HART. I would remark, in reply to Mr. Miller's inquiry, that we have been accumulating considerable piles of ore. Prof. Pasifer Fraser took very careful specimens of every ore. From one vein of these examples he obtained 63 iron, .023 phosphorus; another vein gave 52.5 iron, .09 phosphorus. I simply give these as the latest facts found.

MR. JOS. D. WEEKS. I have brought this map, which shows the present and previous state of railroads in Virginia. The Richmond and Allegheny railroad follows the James river and runs two miles west of Clifton Forge. Another projected road is to follow the west base of the mountains and strike across the country to Laurel Gap. That will enable them to get over with a grade of 60 feet. There are several parties of engineers in the field to see if a road cannot be made to Pittsburgh. The Richmond and Allegheny road must be finished, by the terms of the charter, by next February. Another point in regard to this matter: I have been looking into Prof. Leslie's Iron Manufacturing Guide, and find that in a number of counties of Pennsylvania, in 1856, there were about 70 blast furnaces, and that ore similar to that of Pennsylvania extended down into Virginia, but much richer in quality. The same ore that occurs in the Lake Champlain region seems to come out in the ores of eastern Virginia.

In almost all this region the ores are primary ores; ores that do

not occur frequently in Pennsylvania. In West Virginia at least two roads are projected to Pittsburgh. The Standard Oil Company has saw mills there.

The virgin soil bears an immense amount of timber. The timber is rapidly disappearing from our own section. It is strange that capitalists do not see the benefit of putting roads there. In the western country hundreds of miles are being built from no-place to the end of a squirrel track, where there is nothing to be found but a squirrel barking up a tree. There is another point, and that is, the prospect for our general trade. I believe that the development in the South in the next ten years is going to exceed that in the North, and that it will be up the valley of the James. When you get to Lynchburg you strike the greatest railroad centre of the South, from which you have direct connection with all the railroads of the South. I said recently to Gen. Slaughter, "Do you sell through tickets to Florida?" He looked at me with something like wonder, as he replied, "We sell them by twelve different routes." That shows what a centre Lynchburg is. There is one thing further: I was interested in the course of a conversation with the present governor of Virginia. In speaking of the advantages of Virginia, he said: "Where in the world is there such a sea coast? There is not in the United States a State that has more than one good seaport; here the coast is hundreds of miles in extent, with not only one, but a dozen seaports." If certain projects are carried out, Richmond is going to be the great seaport from which the cattle of Texas, the cotton of the South, etc., will be shipped, and into which the products of Europe can come. Norfolk is too damp, but Richmond is built on granite, and at all seasons of the year is healthy.

Mr. Wm. Kent. I have looked at this subject for two or three years past with great interest, and have been pestered (yes, that is the word) by letters from Virginia and samples of ore, which latter I have handed to some of our manufacturers and had analyzed. The general position of manufacturers here is one of waiting to see what will turn up. They are also willing to invest their money in building a road if the ores are here and if they will pay. But they have not yet had sufficient demonstration of the existence, quantity and quality of these ores. Several manufacturers in other sections have been looking upon this matter in a different spirit and have been sending agents to examine. Some have purchased lands and are holding them at present. I do not know of any Pittsburgher doing

this. The thing for Pittsburghers to do is to send experts there to make a complete examination of the whole field. If four or five public spirited firms would employ good mineralogists and mining engineers to go down there and spend several months and make a report, and if the report demonstrated the value of the deposits, then capital would be furnished without stint. I suggest that this be the first thing done.

MR. JOS. D. WEEKS. It is a fact that there has not been much demonstration in Pittsburgh of the ores. I think the course Mr. Hart has taken is the proper one.

MR. HART. I just want to say that we have sent already six or seven thousand tons to Pittsburgh. I have had every day an application for more, and have not yet heard a complaint. With regard to sending experts, I wish to say that we have recently acquired two large mansions and have a very good colored cook; and any time Pittsburgh wishes to send a delegation we will be glad to entertain them.

MR. JONES. The principal thing lacking has been transportation facilities. One of the chief reasons for this was the attention paid to east and west roads. It seems to me they are beginning to look to roads running north and south. If the scheme is properly put before capitalists it could be carried out, and it ought to be done before we have another season of hard times. It seems a marvel that hundreds of miles of road are built in the west where there is little else than the products of the soil for transportation, and yet we cannot get a railroad to the seaboard built through such a country. It is remarkable that twelve or fifteen years ago Mr. Thomson designed a road running into Virginia, before the vast quantities of iron had been discovered.

MR. JOS. RAMSEY. Pittsburgh's trouble is discrimination and the cutting of rates on railroads. The manufacturers of Pittsburgh will go to any expense to reduce the cost of the manufacture of iron —even a few cents per ton—but when it comes to putting money into railroads, whereby the cost of raw ores would be reduced greatly, they seem to be very much afraid to venture. We have heard a great deal of this country, but we cannot realize it until we have been through it. Pittsburgh seems to have neglected the southern part of the State very much. The railroads run east, north and west, and it is only a few years since there have been any railroads south. Within 100 miles of Pittsburgh there is a country

almost as undeveloped as the Rocky Mountains. If Pittsburgh men will only do their share there is no doubt a road can be built. Pittsburgh ought to have enough interest in the railroads to be able to say that we must have as good rates as any other city. Until they do this they will be liable to have pools formed that will put rates up to figures railroad men wish. I was one of the party that went down to Virginia, and was amazed at the immense deposits of iron ore. The best demonstration that could be given is the sale in this city of 60,000 tons of ore. It is a question for Pittsburgh men themselves to settle, whether they shall handle this ore or let some other town come in and reap the benefits.

THE PRESIDENT. I would like to say a very few words. During my apprenticeship I had to travel all over Pennsylvania, and I need not repeat that we have right here in our own State immense quantities of ores and timber lands. The soil of Pennsylvania itself is hardly scratched yet. And when you go down south the state of affairs is still more remarkable. The road indicated by the red line [referring to a plan of the proposed road] on the west, seems to be the one for Pittsburgh to take. In the large district from the northern part of Pennsylvania to northern Alabama and Georgia, if all of Great Britain's mineral fields were taken and pitched down in the woods they would be lost, and it would take a great many years to find them again. As to the quality of the ores, I believe that by present well known cheap washing processes it will be a matter of total indifference; so that when we do get down into this undeveloped country we can use anything that has enough iron in it to justify working, and get equally good results from it. This is what we need to turn our attention to.

A FEW OF PITTSBURGH'S SEWERS.

By Geo. H. Browne, C. E., Supervisor P., F.W. & C. Ry.

[Read April 19, 1881.]

The subject which I intend merely to introduce, may not stand comparison, with regard to scientific interest, to some of those already discussed by this Society; but, as it is so intimately connected with the future welfare of the community, should receive a most thoughtful consideration.

The question of sewerage generally has been so ably and exhaustively discussed by so many of the world's most prominent engineers, that you certainly cannot expect me to exhibit much originality, nor follow, except with tottering gait, in their footsteps. Criticism is the least difficult side of any question, because that requires no genius; hence, I shall confine myself principally to a genius of fault-finding.

After the outbreak of diphtheria, in August, 1877, the sewers of this city were brought into more prominence than they had been from the incorporation of the city up to that date; then through copious letters and voluminous reports, more remunerative to the printer than beneficial to the public, it was announced that the population was in danger of being decimated by fevers more fatal than ever swept the Campagna, through engineering blunders and ignorance; but modestly announcing that there was a balm in Gilead. Through the inspiration of legislation and Divine Providence, a body corporate still existed to lead the way to sanitary reform and restore the city to its pristine salubrity.

About 1872, the present City Engineer had surveys made of the different water basins within the city limits, with a view of proportioning the size of the sewers to their different necessities, and

reducing the entire scheme to a system. Scheme is the only word which can be applied to a number of subterranean flues intersecting at every elevation and position, and exhibiting no evidence of intelligence or design. The Engineer, I presume, after making an examination was appalled with the chaos to be restored to order; and the vast amount of money necessary to effect a systematic change could only be estimated by taking into consideration the cost of rebuilding every foot of sewer; hence, he simply applied himself to remedy accumulated evils, according as it became necessary to build new sewers, or extensions, as well as could be done by one who is metaphorically manacled and shackled by Councils and committees of Councils.

Let us first lay down the conditions to which a well built sewer system must conform :

1st. It must be of such size that it shall carry off all rainfall and sewage from that district or basin for which it is designed, and not larger than is necessary to meet the maximum requirements.

2d. The grade, especially where a light fall can only be secured, should be perfectly straight.

3d. It should be built of such shape as to secure the greatest possible velocity, especially at a minimum flow, and thus carry off all fæcal matter sufficiently quick to prevent decomposition.

4th. The brickwork or masonry should be perfectly water tight.

5th. The interior must be finished to a smooth and uniform surface.

As the last condition seems the least important of those enumerated, let us carry the investigation further and see what mathematical proofs can be obtained. Take Eytelwein's formula $v=50.93\sqrt{RJ}$, where R=mean radius and J equals fall per foot.

Let a=area of water in sewer.

F=fall.

L=line of contact with water and sewer.

l=length passing through in a certain time.

w=weight of a unit of volume.

h=height of irregularities.

v=velocity.

g=gravity.

The influence of gravity would produce an increased velocity, and an increased velocity an increased friction, until finally a uniform flow, v, would result; therefore, a quantity of water of the length l

would pass through with the force=$a\ l\ w\ F$. A surface perpendicular to the water receives a pressure equal to $\frac{v^2}{g}\ sw$ when s represents this surface and offers an equal resistance to the running water. If h represents the height of irregularities on surface, then surface $s=L\ l\ h$; hence we have equation $a\ l\ w\ F=\frac{v^2}{g}\ w\ L\ l\ h$, therefore $v=\sqrt{\frac{g}{h}}\sqrt{\frac{a}{L}}\ F$; but $\frac{a}{L}$=mean radius and F=fall, consequently $\sqrt{\frac{g}{h}}$ must =50.93 or 5-32″; hence, Eytelwein's experiments must have been conducted in a channel with irregularities equal to 5-32″. Now as $\frac{g}{h}$ forms a very important element in the formula, we can readily see the importance of having a smooth, evenly finished surface. Suppose we take half an inch as the height of irregularities, then we find the formula would become, instead of 50.93 $\sqrt{RJ}$., only 27.8 $\sqrt{RJ}$; therefore, giving little over half the discharge that would have been given had the irregularities not exceeded the 5-32 of an inch. Again, by glancing at the formula, we find the shape becomes another desideratum. Of all superficial figures the circle must give the greatest mean radius, because it encloses the greatest space with the shortest length of line. In a circular sewer, however, it must run full or half full in order to give the greatest mean radius. Then from half full downwards the mean radius decreases, thus giving a smaller discharge; hence, we would come to the inevitable conclusion that two sewers should be constructed, one for a maximum flow, and one for a minimum flow. While this would be scientifically correct, yet the benefit arising would evidently be more than counterbalanced by the cost of construction. However, by adopting the egg-shaped sewer, which is simply a compromise between two such sewers, we practically embody the advantages of both at a much less expense, owing to the simplicity of construction.

In regard to the third condition, Krepps on "The Sewage Question" says: "Many engineers have placed their hopes upon the speed of the sewage current not allowing sufficient time for the generation of any great volume of gases; but this is another fallacy, proved to be such by sad experience wherever the theory has been reduced to practice. It might already have been found out by the opening of a bottle of soda water, which shows more bubbles rising to the surface the more the bottle is shaken and the liquid agitated." I am unable to see that such a statement conveys any proof. The "sad experience" is neither particularized nor associ-

ated with the case, and the "bottle of soda water" affords no more parallel than the chemical constituents of soda water bear to the chemical constituents of sewage water. That the evolution of gases would be increased by violent agitation is unquestionable, but then the fluid must arrive at a certain state of decomposition before gases can even be shaken out, and the object is, to carry off sewage matter from the city sufficiently quick to prevent the evolution of gases, even by agitation. A certain time must elapse before decomposition takes place to any appreciable extent, and if the velocity can be so increased as to carry off all excrementitious matter within the limit, a great deal is certainly accomplished.

Let us first consider the main sewer running down Twenty-first street and insanely curving into Sarah street, thence curving again into Nineteenth street, which, strangely enough, it follows in a straight line to the river. No sane engineer would make such a location. It must certainly, reading by the light of other events in this city, have been made by some pernicious councilmanic interference, instigated by constituents who thought they were subserving their own interests, when, in reality, they were culpably blind to them. This sewer has a circular cross-section, when, judging from what we have already said on the subject, it should have been egg-shaped. In regard to size, let us investigate how closely it approaches to scientific requirement, the diameter being 6 feet.

Now according to plan (furnished through the courtesy of Mr. Dempster), the entire territory drained by this sewer is about 219 acres. Suppose this sewer to have been built, having the city's future growth in view, and the entire territory to be laid out in lots of 20x100 ft. and streets 60 ft. wide, and entirely built up. Let maximum rainfall equal one inch per hour. Assuming street 100 ft. long and 60 ft. wide, and that half an inch of total rainfall on street finds its way instantly to the sewer, $\frac{2}{3}''$ from house tops, and $\frac{1}{4}''$ from back yards: then from street 60 ft. wide and 100 ft. long, 250 cubic feet per hour=.0694 per second; house $20'x60'x\frac{2}{3}''x5=333\frac{1}{3}$ feet per hour=.0926 per second; back yards $20'x40'x\frac{1}{4}''x5=83\frac{1}{3}''$ per hour=.0231 per second; sewerage per head at an average of ten persons to each house, 8 cubic feet per day and half as much more for 8 hours per day=.0053. Total for 100 feet of street, houses and yards=.1904 per second. The area of territory considered is equal to .36731 of an acre, hence 219 acres would require provision to be made for 594 times as much, or $594\times.1904=113$ cubic feet per second.

As a basis, then, to obtain a formula which shall give the diameter due to the maximum discharge, take $v=48.49\sqrt{DS}$ where v=velocity D=diameter in feet, and S sine of inclination. Let c =cubic feet discharged per second; hence the area being $.7854\,D^2$, we have $\frac{c}{.7854\,D^2}$=velocity; therefore, $\frac{c}{.7854\,D^2}=48.49\sqrt{DS}$, whence $D=\left(\frac{c^2}{1450\,S}\right)^{\frac{1}{5}}$; hence substituting for C^2113^2, we have D=3.38 ft.=diameter of sewer for maximum flow, which is evidently sufficiently large for any emergency; because, applying Rowe's formula for acreage, it would only give a diameter of 3.13 ft., and Eytelwein's 3.25 ft. A circular sewer 3.38′ diameter would be equivalent in cross-sectional area to an egg-shaped one having greatest diameters 4.19 and 2.79 ft., affording ample room for repairs and examination. If a sewer of those dimensions had been built in a straight line following Twenty-first street, the benefits arising could not have been represented by figures. Let us examine the sewer from a pecuniary standpoint, following the longer line of Sarah street.

Taking the length to be 3160 ft. and 12 ft. deep, we have a loss due to unnecessary excavation=3680 cubic yards at say 40c.=$1472, and 332,000 of brick, say $12 per M for work and material =$3984, showing the cost of blundering in this single sewer to be $5456. Let us next examine the lateral connections. Here we find the entire territory to be drained 79 acres, and assuming the grade to be only one foot per one hundred, and employing the former method of determining the size, we find the diameter to be 2.58 ft. instead of 5 ft. for about 1000, and 4 ft. for about 1200 ft. What empirical formula led to such gross results would be most difficult to determine; but one thing is certain, assuming our previous rates, that on the 5 ft. sewer the city incurred an expense altogether unjustifiable by any process of reasoning of $1580, and on the 4 ft. portion $1400, then we have two sewers each 3 ft. diameter and about 1200 ft. long, which, had 12 inch pipe been used instead, both the interests of science and economy would have been better attained. On these two sewers the loss is, at the lowest estimate, $4200, making a grand total, chargeable to ignorance or some illegitimate interference, of $13,636. Then next comes the Washington street sewer. I shan't endeavor to follow its course, because it beggars description. Its location can better be followed on the plan. The eye sees more than language can paint. This tortuous duct drains about 129 acres, and its size should have been 3.16 ft., taking an

average fall of 1 ft. per 100, instead of 5 ft. diameter. Loss incurred at lowest calculation, $4400; total on both sewers and connections, $18,036.

If time permitted to follow out the sewers planned and executed by past genius, I think I could figure up a sufficient amount to establish an endowment fund to pay the city engineer and his assistants an amount above second and third-class clerks.

If the loss was simply a pecuniary one it would be, comparatively speaking, a matter of little importance; but on account of being three times the necessary size, and the workmanship poor, the velocity is retarded, and instead of carrying off the fæces, it is being continually deposited along the entire length of the sewer, where it remains, and is allowed to remain, generating the most noxious gases. The sewer then becomes nothing better than a cess-pool. It is not uncommon to find 10″ of excrementitious matter in some of the sewers. Then what is the result? Where the salts and acids which human excrements contain come in contact with stone, lime and mortar, their combination with oxygen results in the formation of nitrous acid, which shows itself by a white formation covering the surface. This substance has the most damaging influence on the masonry, and in the course of time causes a most complete disintegration. Then we have the most malignant results arising from a soil saturated with sewage matter. If a sewer is known to be badly shaped, having a light fall and ill-conditioned generally, as all the old sewers are, more care should be exercised in keeping them clean, either through mechanical agency or flushing. During the summer the stench plates frequently become the most useless appendages on account of the water being drawn off by evaporation, thus leaving an opening through which the gases generated within can escape and sow the seeds without, which soon germinate and ripen with a fatal harvest.

We have shown that the sewers are three times larger than requisite. Notwithstanding, however, a certain member of the Board of Health makes the following statement: "During the afternoon of July 27th there occurred a rainfall of 50-100 inches in a storm of one hour's duration, sufficient to test their utmost capacity. Again, on August 15th, rain fell to the amount of 60-100 inches in 65 minutes. There occurred, therefore, during the year 1877, one heavy rainfall and three sudden and violent storms of short duration, but amply sufficient on each occasion to cause an immense volume

of water to be discharged from the steep hillsides into the sewer; the effect of which, as previously described, would be to force the sewer gas through the connections directly into the dwellings." From the foregoing calculations we can see that such statements never had their origin in facts, and, therefore, any arguments based on such premises are worthless. Then, apropos to the above extract, comes a recommendation characterized by extreme assumption and empty arrogance, namely, "that the Board of Health petition Councils to establish by ordinance, that no sewer should be altered, constructed or improved, unless with the recommendation and approval of the Board of Health." This is only one of the numerous instances where the Engineer is trammeled by an iniquitous interference most prejudicial to the public welfare, by men, too, who should be sufficiently educated to see their own ignorance; but as that is the highest education which a man can receive it is therefore seldom attained. Is it any wonder, then, that we hear of "blundering engineering?"

Let us follow this report a little further: "A pipe sewer four feet in diameter, being a continuation of the Eighteenth street branch, extends a distance of 275 feet up the steep hillside to Pius street. This sewer would appear to have served as a chimney or ventilator for those on the flat ground below, as deaths were the most numerous in the immediate vicinity of its terminus." Then again: "Both the Washington street and the Twentieth street sewers are without ventilation. Manholes are provided at intervals, but are covered with tight-fitting cast iron lids. Sewers will always be dangerous enemies in our midst—the danger increasing in proportion to the age—until the sanitary engineers show us how to ventilate them." Here we have pointed out the fatal results of ventilation, and immediately following the absence of ventilation is a source of grievance. Tight-fitting lids are condemned. Then what substitute can be offered except grating? In regard to gratings Mr. Wm. Menzies says: "That if any engineer would set himself to the task of devising the best means of discharging in the midst of the population all the stench from sewerage drains, it would be difficult for him to plan a more complete method than street gratings afford." First ventilate the sewers and the next absurd step would be to ventilate the graves in the different cemeteries. Even suppose ventilation could be accomplished, decomposition still goes on, and the gases are disseminated but not annihilated. Mr. Henry Austin, consult-

ing engineer for the London Sewer Commissioner, in a most elaborate report concludes as follows: "That the system of ventilating sewers by means of shafts and grates was objectionable and should be discontinued." "That ventilation by means of furnaces and chimneys at great distances would be attended with great difficulties, labor and cost, without promise of satisfactory results."

From what has been written, the conclusion is inevitable that the Board of Health would be poor guides to follow in matters of sewer reform, and hence that the Engineer is the only one who should have a voice in such matters.

Any argument depending upon the hypothesis that the sewers were taxed to their "utmost capacity," and hence that the gases were forced into the houses, is, we have shown, worthless; therefore we must look for some other cause.

The territory outlined in black on accompanying plan has all been filled in, or made ground, within a comparatively short period. The Monongahela river carries in suspension a fine silt which has been deposited, during immersion, over this entire area, forming a stratum almost impervious to water, and certainly impervious to sewage. Over this layer there is probably from 15 to 20 feet of embankment; hence the sewers lie above this stratum, since none of them are over 12 ft. deep. These sewers being badly built, the poisonous fluid has been escaping for years, and being unable to percolate through this silt, has spread laterally and vertically, leavening the entire superincumbent mass of earth, so that there is not a house on this territory but which encloses within its walls sewer deposits. At different points there are back-houses unconnected with the sewers, each yielding its quota to the thorough saturation. Then, located in this district are several springs which supply drinking water to a numerous population; hence death is both imbibed and inhaled, since we have gases generated in the houses and around them, independently of sewers or sewer connections.

In Tottenham, England, a certain portion of ground was manured by sewage products, and as a result diarrhœa and typhus prevailed. The following is an extract from a report on the subject: "During the past year (fall of 1866) typhus and diarrhœa have prevailed at Page Green, a detached hamlet in the Parish of Tottenham, numbering some 90 houses, which, according to Dr. Seaton, who was instructed by the council to make a sanitary investigation,

was owing to the land in the immediate vicinity being treated with the sewage of Tottenham, and also the inhabitants drinking water from wells dug just beneath the surface of that land. Thus of 24 houses having such wells, not less than 19 had either one or more cases of sickness." On the South Side we have a similar evil in an aggravated form. That the diphtheria occurring in '77 to '79 must have had its origin in this way is shown by its appearance in the wealthier families in the East End and points where, if investigations were prosecuted, the cause might be found to exist in the lack of a sewer system, the nature of the soil preventing any purification by percolation, and the poisoning of the springs by a surface flow of water. Then was it not more than probable that the heavy rains should wash off the surface, which had already been slowly depleted of its gases, thus presenting fresh sewage matter to the chemical influence of a burning sun which invariably immediately followed those rains referred to by the Board of Health, thus speedily generating those gases and disseminating that diphtheritic miasm, germ, particle (call it what you will), that produces disease and death ?

In regard to sewer gases there is only one verdict : confine them if possible, but should they accumulate so as to force their way out, provision should be made in order that the escape may take place in the streets or back yards without entering the houses. This can be done by a very simple contrivance without doing away with stench plates or "tight-fitting castings." On the contrary, I would suggest that their use be rendered obligatory in every sewer which is and shall be constructed within the city.

All traps in the internal arrangement of houses should be removed except one in the soil pipe at D, and use an open trap A outside, as shown by accompanying plan, and to the main pipe leading into it all others in the house must be connected before reaching the trap. The manhole B affords means for cleaning and inspecting, and the grating at C allows any gases to escape which through any possibility might force their way from the sewer; and with ordinary care it is almost impossible for any gases to be forced within a building possessing such an arrangement. The ordinary syphon trap, if it possess any merit whatever, is certainly of a questionable nature, because, should it happen to run full, which is a common occurrence, a vacuum is formed, the entire water drawn from the trap, and an unobstructed connection is made between the house and the

sewer; then, as there is almost invariably a current of air running through the sewer in the direction of the houses, they are filled with gas from basement to garret in a very short time. However, with such a plan as here proposed, I cannot see how such an accident could possibly occur.

In regard to lateral connections, Mr. Krepps says: "Sewers of unequal size should never be level at the inverts, for this causes the sewage of the larger to dam back into that of the smaller tributary. To avoid stoppages both sewers must be level at their crowns and the tributary have a fall at its junction with the main, this necessity of course increasing the depth of the main sewer and in consequence the difficulty and cost of construction." It may be assumption, but notwithstanding Mr. Krepps' recognized ability as an engineer, I must file my dissent. The method which Mr. Krepps advocates, as shown at E, is objectionable for two reasons: First, because it acts as a duct to carry off all gases generated in the main sewer; and secondly, because the sewage falls with a splash; hence, all the force which it had acquired in falling is lost which should have aided in increasing the velocity in the main sewer; besides, a deposit is formed, as shown at F, in the up stream side. If the laterals are connected with the main at right angles a damming must occur, but where such junctions can be obviated they should never be used; but, wherever possible, all laterals should enter the main sewer with an easy curve in the direction of the current, as shown at M; and there are few cases, if any, where this cannot be accomplished; and the tributaries should always be level with the main sewer at inverts; then, when there is an average flow of sewage the laterals become effectually trapped. The laterals are generally short, and hence they generate very little gas, since the sewage is quickly carried to the main sewer. The great bulk of gases are generated in the main sewers, because they carry a greater quantity of sewage for a much longer time; hence we can see the importance of preventing the ascent of gases in the connections or laterals.

The science of a correct sewer system will, however, be applied in vain, if some of the plainer lessons which common sense teaches be neglected. A network of sewers may be constructed with consummate skill, so that each may perform its functions to a mathematical nicety, and the connections may be as perfect as the ingenuity of man can devise, and still there may exist a most grievous deficiency, as we find in Pittsburgh—waiving all considerations as to perfection—

where each of the main sewers is carried to the river and discharged at various points. There are few cities in the United States, if any, better topographically situated than Pittsburgh for a thorough sewer system, and to that fact alone can be ascribed its comparative freedom from contagious diseases. It certainly owes no debts of gratitude to its early engineers, who simply carried each sewer to the river, where they left it to pour out its putrid contents where the current was most sluggish. As a result, we find sewage matter held in suspension about the mouth of each sewer, or deposited along the shores, rendering the entire river front a most indescribable nuisance during the summer months. Actuated by a sense of decency or an instinct of self-preservation, some of the filth was removed the shortest possible distance from the houses. It surely could not have been imagined that the requirements of sanitary science ended there. To think so would impute too much ignorance. Let us be charitable and ascribe the mistake to false economy.

All attempts at sanitary reform will prove as useless as expensive, until two main sewers are constructed, one parallel with the Allegheny, and one parallel with the Monongahela river, intersecting all laterals, and discharging their united contents into the Ohio river where the current is swiftest. Had this plan been adopted at an early date, it could have been accomplished at an expense very little greater than required to build up the present system, where each sewer is carried several hundred feet further than would then have been necessary. A similar plan should be adopted on the South Side. The plan may now be expensive, but the necessity is urgent.

DISCUSSION.

MR. ALEX. DEMPSTER. I do not know how to begin the subject better than by stating the difficulties that have been met in the project of bettering the condition of the sewerage of Pittsburgh, especially in those localities which the sewers specially referred to in the paper read are located. One, I may say *the* objection, has been the lack of inclination of those who would be benefited by proper sub-drainage to pay the cost of construction. There have been places where cellars have been filled with water giving off malaria, and when the residents were approached as to what they would be willing to do towards putting in a sewer or sub-drain to relieve them from the disadvantages and dangers attendant on

existing facts, they have refused to do anything for their own relief. Each one wanted a sewer on the street on which he *did not* live, and for which he would not have to pay anything. This will explain why sewerage has not been more general. As to the defects of the sewers mentioned in the paper, they were built under different administrations governing the different borough corporations previous to consolidation with the city. Each borough on the South Side was under a different head, and the result was that sewers were constructed without special reference to actual requirements or future or combined adaptation. Consequently many defects have been injected into the system, the evils of which we now reap; not attributable, however, to any one man, but to the unfavorable combination of circumstances under which they were inaugurated, and which cannot be traced back to any definite point. I would not attempt to saddle the responsibility on any one.

Now, as to the present administration—from the causes already mentioned, the failure thus far in performing anything satisfactory to ourselves, and consequently to others, has arisen: whilst there are some who would criticise the imperfections clearly visible in that locality, they cannot and will not provide a remedy therefor. Several attempts were made to remedy the existing defects, but failed. In any community an engineer may want to do that which he believes to be his duty, but cannot on account of overruling powers. There are parties who would wield the sharp knife of criticism regardless of where it cuts, and ignorant of whether it thrusts the proper party or not, their ambition being to show their ability to thrust.

We have with us Mr. J. J. R. Croes, of New York, Treasurer of the M. S. C. E., whom I will introduce, requesting him to furnish us with his ideas on the general subject of sewerage.

THE PRESIDENT. I take great pleasure in introducing Mr. Croes to the Society, and hope he will favor us with his ideas.

MR. CROES. Mr. President, I did not expect when I came in here with my friend Mr. Dempster, that after bringing me in he would attempt to bring me out. I have not had an opportunity to examine the paper which is under discussion, and I hope you will excuse me for the present. I think it would be more interesting to you, sir, and certainly for me, to hear some of the gentlemen who have studied this paper, than to listen to me.

MR. CHARLES DAVIS. I am very glad to see that some one has taken up this subject. I think it will be found, before we get

through with it, that it will make quite as much talk as the metric system, and result in as much good.

Mr. Browne's paper has a great many good points, but some things he speaks of there do not agree with my experience. What I shall say will be to give my own experience and observations. Some thirteen years ago I was compelled to take up this subject in Allegheny. Sewerage had received but little attention up to this time in this section. Further west there had been more done. Mr. Chesbrough in 1857 had made a report on Chicago sewerage. Col. J. W. Adams had also started a plan of sewerage for Brooklyn, and had made a report; I think that was subsequent to the report of Mr. Chesbrough. I visited these gentlemen and got all the information I could, and inspected their work. They said my subject was a new one here and that I would have some difficulty in getting information from towns in this country. They thought the best information would be the Parliamentary Reports, which I found in the Astor Library. I also found some good articles from English sources in the "Civil Engineer's and Architect's Journal." I then started on the work in Allegheny. Mr. Dempster has stated what he conceives to be the difficulty in the way of getting satisfactory sewerage for Pittsburgh. I think he is mistaken—the troubles are in quite a different direction. In the first place what is required is legislation to carry out or comply with plans and defray the expense of constructing a proper system. Pittsburgh is many years behind other cities in this respect. I do not want to be considered one who favors more legislation, generally speaking—we have too much special legislation. How utterly absurd it is to think of constructing sewers by a board of viewers assessing benefits! Especially as every new sewer under the present law may have a separate and distinct board. The prime object of sewerage is to carry off the daily waste of the city. If we make waste we must get rid of it quickly and economically. The first thing to be done in Pittsburgh is to ask for legislation to provide for the expense of constructing the necessary sewers. In sewerage (this term is intended to comprehend drainage) there are two classes of benefits, one general, the other local. For instance: in all cities you have to take care of the natural water-courses, and to drain low grounds and swamps, or marshes, also you have to provide facilities for taking away the daily waste; the first is a general benefit— a general sanitary measure—and the other a local benefit. The question is

how to arrange for distributing the cost of these works. In Allegheny our plan was first to determine the proper size of sewer to carry off the waste of one block, or say two half blocks of business buildings with the contiguous yards or areas, and having a favorable street grade for drainage. With a block compactly built, say capable of containing a population of 30,000 to the square mile, a 15 inch sewer was found ample. The cost of such a sewer was made a basis for local assessments—this was made on the frontage; when an arterial sewer traversed a street that would otherwise be accommodated by a 15 inch pipe or lateral sewer, the property fronting was assessed the cost of a 15 inch sewer pipe, for that was all that was required to give them drainage facilities, (the cost was $2 per foot front at that time), the balance of the cost was assessed by a millage tax provided for every year—a general sanitary tax. Larger lateral sewers costing $4 per foot run, were put in later, as needed. That is the way the plan was started and the way it is working to-day—one a general millage tax, and the other a frontage tax for lateral sewers. Lateral sewers are built when petitioned for by property holders, main or arterial sewers are built at the option of Councils without regard to petition. In cities like Pittsburgh, of course there are certain localities where improvement will be far in advance of other localities. The proper way is to divide the city into districts, and have district taxes for mains. Here you may have between districts large stretches of intervening property not benefited. It would be wrong to assess East End property for sewers in the heart of the city. Before such a plan can be adopted in Pittsburgh you must make some arrangement for sewerage assessments; get the money back into the treasury from the odious board of viewers system and start anew on a clean sheet. Mr. Dempster speaks of Pittsburgh's sewerage system, but where are the sewers ? The sewers mentioned in the paper under discussion drain 420 acres, or about two-thirds of a square mile; the city covers 22 square miles. The difficulties of readjustment cannot be so great. Where is there a city of its size that has not more sewers ? Cities do not come ready made, but must grow. The people did not start to make a system of sewers; they were only constructing drains, and may have made mistakes. The way we are fixed here we are compelled to take into account the many deep indentations or gulches dividing the building territory. The drainage and sewerage should generally follow the natural ravines. I think, however, many of these ravines should

not be closed up; we should do as they do in many towns in Switzerland, use them for highways in the dry season of the year, and for waterways during the period of flood. In such cases there would be separate channels for the sewage proper. We have also some atmospheric difficulties, being subject at times to cloud-bursts of water. In regard to the Board of Health's report, I think it is a good one; the only thing I did not like was that they did not come to Allegheny for information. I think they are certainly on the right track; what they ask for is nothing more than they ought to ask for. The matter is one of much greater magnitude than we are at first thought inclined to regard it. The time will come when we will have to take up this sewerage question seriously. The sewage should be carried away from the city; but is the Point away from the city? That is in the heart of the city. Saw Mill run comes into the Ohio a half mile below this place, and on the Allegheny side there are three miles of solidly-built town below the Point. We must go away below the projected dam. What should be done, then, is to construct such a system as will take the sewage proper away, and let the storm water go into the river. For the present, pipes of suitable size should be extended from the mouths of sewers on shore line well into the current of the river to take away the sewage proper—the storm waters to be discharged as at present. Mr. Browne says that the sewers are too deep. Mr. Krepps (an author he quotes with great confidence) gives 15 ft. for main sewers, while others state 20 ft. a good depth. As to the shape of the sewers: the oval is preferable for sewers up to 3 ft. and probably up to 4 ft.; after you get above that, for ordinary sizes the circular form is, except in special cases, the best; the work can be done better and cheaper. If you see the work of others you will see what I say is correct. The best sewered cities are Brooklyn, Chicago and Providence. I think Providence has the best executed work. In Providence they were very particular as to the way in which the work was carried out—it was constructed in a business-like, legitimate way. We should find out what it would cost to put in similar sewers in Pittsburgh. Twenty-five miles in Allegheny cost $860,000; it could be done better and cheaper now.

Mr. Dempster is trying to get in the right track. He has got to make reports, and to come out and say what is required. The Board of Health does not know what it wants, but it wants something.

Mr. Browne. Mr. Davis certainly labors under a misapprehension when he states that I have asserted 15 ft. too deep for sewers. As the depth to which a sewer should be constructed depends upon circumstances, no general rule can be laid down. A sufficient depth to drain the deepest cellar and to prevent the water, should the sewer run full, from backing into the cellar, might be used as the minimum.

Much of general interest might be developed if the discussion were confined to the question of ventilation or non-ventilation. My opinion is that it would be just as expedient to ventilate the graves in the different cemeteries just because certain gases were developed during decomposition. If it is judicious to liberate the gases in sewers, it should also be equally judicious to liberate the gases in graves; because the gases are certainly not less noxious in one case than in the other.

Mr. Davis. My experience so far has been, that ventilation through manholes is the best. Of course if the sewers are properly constructed there will be very little trouble about ventilation. In the upper reaches of the sewers, in some cases, when the gases are specially foul, charcoal is used. If you put in an 8 foot sewer to do the work of a 2 foot sewer, you construct a huge gas trap and nothing else. London has worked all around this and has taken to the manholes. There is more danger in the upper reaches of the sewers, and they should be carefully watched; it can be obviated by putting in flap valves at the bottom of the inclines. There is no trouble about ventilation if you can start a clean system. The sewers in some parts of Allegheny have no foul smell. Property, as a general thing, is far more desirable on the line of the sewers. On this side, I venture to say, there are not 1500 authorized water closet connections with the sewers. The South Side is full of cess-pools, and the soil is so saturated with the filth that you can smell it.

Mr. Wm. Kent. I notice that Mr. Browne says the Board of Health would be poor guides to follow in matters connected with engineering, and that engineers should know everything, from hod carrying to buying a legislature. If there is one branch of engineering in which outside expert assistance is needed, it is sanitary engineering. And this matter of sewers is a question in sanitary engineering, involving the chemistry of gases, statistics of death, and our knowledge of the mortality of diseases, the causes of dis-

eases, etc., which is yet in its infancy; these questions all coming into the question of sewer reform.

The Board of Health, and all other sources of information, must and should be consulted by the engineer who desires to do his duty. The members of the Board of Health ought to understand this question from the standpoint of the physician and statistician. I think it quite likely that, in the economy of nature, if the sewer gases get access to the free air they will be annihilated by the oxygen, and changed to gases which are harmless. This is a question for the gas chemist. If this is the fact, then thorough ventilation is the proper thing. The engineer is supposed to know how to build a sewer, but he is not necessarily a chemist or a physician, and he cannot do without their aid.

MR. DAVIS. The Board of Health speaks of certain classes of material being put in the sewers which should not go into them, such as the refuse from slaughter houses. In Allegheny the butchers have made Butchers run a vehicle for carrying away the offal from their slaughter houses. This should not be done; sewers are not created for that purpose; the offal here, as in some other cities, should be carted away, and what cannot be utilized should be burned. Pipes are being generally used for sewers. In Brooklyn, N. Y., nearly two-thirds of the mileage is pipes; about one-half in Allegheny (of 25 miles 12 are pipes), and about the same proportion in Providence. In Chicago three-fourths are pipes. We should encourage the Board of Health and work with it.

MR. BROWNE. We don't care anything about the chemistry of sewers, but what they do, and not why they do it. If Mr. Kent will read the reports of the Board of Health he will find them full of contradictions, one page containing arguments in favor of ventilation, another arguments in opposition, which shows that they are written by those who are thoroughly incapable of writing intelligibly on the subject. I like to hear talk, but I like a little logic and common sense with it, although I know common sense is a rare commodity. [Mr. Browne here went to the black-board and illustrated his ideas by a sketch, claiming that gases would not force their way through traps and connections if constructed in accordance with his plan.] The Board of Health is an excellent body in its place, but wrapping it around with legislative enactments doesn't make it a judge of sewers or sewer gases. If the sewer system is properly constructed, there is no necessity for ventilation, because

the gases cannot be compressed, and under no circumstances can a trap be forced.

MR. KENT. All engineers' reports say that compressed gas will force traps.

MR. BROWNE. What kind of traps?

MR. KENT. The ordinary trap.

MR. BROWNE. Oh, but I am talking of an extraordinary trap.

MR. KENT. I claim that it is better to annihilate the gas than to let it out by trap or confine it in the sewer.

MR. BROWNE. But I don't want to annihilate the gases, because that is impossible.

MR. KENT. The point I make is, that engineers don't know all there is to be known about sewers, and the Board of Health should be consulted.

MR. DEMPSTER. I think that Mr. Croes might now give us a little speech.

MR. CROES. It appears to me that in Pittsburgh you are trying to put the cart before the horse. Before you have the means to carry it out you are trying to adopt a system of sewerage. There has been no clear statement as to the exact sanitary condition of Pittsburgh, and what means should be taken to remedy the defect.

There can be no system or intelligent discussion until first there is made a plan and topographical map of the city, by an intelligent engineer, and a system of sewerage devised upon that; and that will never be done until it is paid for by the city. It will never be made up by any association, or any single gentleman. Those interested in the matter should take such steps as would force the city officials to have a definite system established and a definite plan made for the sewerage of the city.

The city of Pittsburgh, judging from the remarks made here to-night, is in a worse condition than most villages of 10,000 to 20,000 inhabitants are, as regards sanitary improvement, because there is hardly any place of size where attempts are not making to find out what is the matter, and how to correct the evils. As for the Board of Health, it is a very good thing to have doctors and engineers; their knowledge would supplement one another. Doctors alone are a little worse than engineers. One remark in Mr. Browne's paper is that a well built sewer system "must be of such size that it shall carry off all rainfall and sewage from that district or basin

for which it is designed," but I do not think that that is positively proven with regard to sewage. That there should be separate systems of drainage, that the sewage should be kept entirely separate from the rainfall, and that the drainage should be provided apart for storm water, has been a subject of controversy for thirty years.

To provide for all the rainfall here, where you have violent and excessive storms, would necessitate the construction of a system of sewers of so great size as to be very costly. Even in Providence the sewers have proved too small for the heavy rains, and there have been very great modifications of the system, as first constructed. In Brooklyn it has been necessary, at great expense, to repair the damage occurring in consequence of overflows. The separate system which has been advocated by Col. Waring for Memphis and some other towns, has certain advantages in certain places. I think there are cases in which it is a very excellent thing. Whether it would be so in Pittsburgh could only be decided by examination of the map and discussion of the question.

As regards ventilation, I do not know when I have been more surprised to hear the best experience of the last twenty-five years controverted as it has been by Mr. Browne. The idea that sewers must not be ventilated is so antiquated, and is so contrary to the experience of many years back, that I do not know exactly where to begin in reply. The argument that sewer gas cannot blow out a trap is not to the point at all; the danger is from the passage of sewer gas into the house through the water in trap being either syphoned out or saturated. The doctors say that the gas does enter, and that it is dangerous when it gets into a house.

MR. BROWNE. But I do not mean the ordinary house trap.

MR. CROES. You have got to take things as they are, and as they will be for some time.

MR. BROWNE. But that cannot surely be construed to mean that science admits of no progression.

MR. CROES. Oh, well, if you are going to reform the whole world. In sewers as they are there is gas, and it is going to come out the first place it can. If you can dissipate this gas, you can make your sewer purer. To free it from sewer gas you must prevent the generation of deleterious gases.

MR. DEMPSTER. As a vast amount of gas has been exploded to-night, I would like to disseminate a little more. I now propose

to answer some of the criticisms that have been made from a lack of knowledge of existing facts.

First, the city is in as good a condition as any in the United States for the construction of a sewer system. I would like to say to my friend Mr. Croes that we have a good, thorough topographical map of the city showing the water sheds and drainage basins. As to ventilation—opinions vary. The epidemics on the South Side in 1877 were said to be caused by lack of street ventilation. A few years ago an epidemic in the lower part of Allegheny City was attributed to street ventilation. Put these two facts together, and what have you?

We all know there is very little new, in fact nothing new relative to sewerage. We can quote engineers who say one thing, and others who say another thing. We have as good authority on each side as any one would want. As to the city of Pittsburgh, it is not like many other cities; we have no long lines of light grades, where the water runs slowly; you cannot keep sewers full—there will be spaces in them where gases will generate. We have a projected system adaptable to all that is required, and we can put it into practice if we are allowed. I would be sorry to see the assertion disseminated that Pittsburgh is so much behind the age, for such is not the fact. Now, as to the assessment of benefits, the law is in theory very good, but the application is quite the contrary. All property within an area to be drained is benefited and should be assessed as a general benefit. Each district should be assessed for the cost of the sewer, as a general benefit to that district. Putting an arbitrary figure upon it I think is not proper. Property that is benefited by lateral sewers should pay for every connection made, or so much per foot front. I think, as Mr. Davis said, the question has proved to be fully as interesting as the metric system, and I hope to take it up at some other time.

Mr. Davis. Assessments of benefits by viewers work in about this way: Take an arterial sewer in a thickly populated district; the sewer is constructed; the board of viewers who assess benefits to cover the cost of sewer is new; each man uses his own judgment and imagination in making up the award. This arrangement is submitted to without any remonstrance. The property holders in the vicinity, but not on the line of the sewer, seeing the advantages of this sewer, petition Councils for a lateral or branch sewer. Councils grant the petition; the sewer is constructed; another board

of viewers is appointed; they look at this matter of sewerage in a different light, and when they come to make up their award they are at a loss what to do; they find it impracticable to make up the assessment without overlapping on property assessed for the first sewer. After this second sewer a third branch sewer may be needed, and the overlapping process is further extended, and so the thing goes on until it gets to be unbearable and the work is brought to a stand; and that is the difficulty to-day. What we want is legislation, and then a well developed plan for the whole city.

MR. CROES. I am glad to hear from Mr. Dempster that you are not so badly off. I do not understand why there is a topographical map and yet no definite system for the city. I believe that the building of sewers is dependent upon resolution of Common Council. I would like to know if the sizes of sewers are fixed by the Engineer or by law of Common Council, and if so, whether the Engineer has any say about it; if he has a fixed and definite plan, whether the next Engineer might not change a certain sewer and derange the system in that way? If so, would it not be better if some definite plan were fixed upon, and made permanent by Councils or the legislature?

MR. DEMPSTER. Whilst the sewers are provided for by Council, they are made by the Engineer. The people petition for a 12, 15 or 18 inch sewer—whatever would be necessary for the purpose. The largest pipe sewers are 20 inch. I know that several members are more than charged with the subject to-night, and I suggest that we postpone this discussion until the next meeting in September. It is an interesting and valuable subject.

CHAMBERSBURG, PA., May 13, 1881.

Mr. President and Gentlemen:

I trust that absence from the city will be ample excuse for my burdening the Society with a letter, for if I could consult personal wishes I should be with my brother members at every meeting, and listen with profit to their interesting discussions.

My object in writing is to put myself on record in the discussion of the paper of Mr. Geo. H. Browne on "A Few of Pittsburgh's Sewers," read at the meeting of April 19th.

With due deference to Mr. Browne's abilities, I think he has gone astray from his subject to attack, as he does in several places,

the efforts of the Board of Health to remedy the evils complained of in the sewerage of our South Side wards.

I would direct attention, without quoting, to his language on page 214, third paragraph, which, though possibly not so intended, is naturally calculated to prejudice the disinterested listener against everything on this subject emanating from that body. Ridicule seldom serves a good object, and least of all in the discussion of scientific questions before scientific and practical men.

But this is only a minor fault I have to find with Mr. Browne's paper, and easily condoned. I would gladly shake hands with the gentleman if I could reach him.

He must certainly have been aware, though possibly he may not have been, that last May a special committee of the Board of Health submitted a report on the origin and prevalence of typhoid fever in the South Side wards, and that said report was printed and distributed, though he makes no allusion to it.

Having been professionally employed by the committee in question to assist them in their investigations, and from intimate acquaintance with the members composing the committee, I am prepared to say that they were far from setting themselves up as empirics on the subject of sanitary reform. The type of the disease was peculiar, and its origin obscure, leading to quite diverse views of it among the medical profession, so that the committee was extremely cautious in their recommendations, and sought rather to lay before the public, (as their report will show) besides the known facts, the latest approved theories and practical information on the subject of sewer construction, etc., to be obtained from the best sources of information.

I wish to say that I give my unqualified endorsement to the plan proposed by Mr. Geo. E. Waring, who undoubtedly is the leading sanitary engineer of this country, viz.: the plan of separating sewage proper from storm water discharges.

From personal knowledge of the dry weather discharge of the South Side sewers, I am convinced that Mr. Browne's proposition to make them somewhat smaller and oval or egg-shaped, would prove insufficient to prevent the deposition of offensive matter and consequent decomposition with its train of evils. It is strange that Mr. Browne should have ignored this branch of the topic—this new school scheme—this proposed *revolution* in the plans for draining our cities. I think the more it is considered the greater its advan-

tages will appear to be. It is fortunate that the small pipe plan is also the least expensive of any heretofore proposed, and adapted to towns and villages of small means as well as to cities where wealth abounds.

Mr. Browne's closing paragraph is entitled to attention. In recommending, as he does, the adoption of main sewers along the river banks receiving lateral branches to be discharged into the Ohio, he is reiterating the expressed opinions of the special committee of the Board of Health, though he had in view the old antiquated *tunnels*—so-called sewers—for the purpose, rather than the 18 inch tile pipe sewer proposed by the former.

To close this discussion I will merely request to have read the 2d and 3d recommendations (page 100*) of the committee referred to, which embraces everything of interest to engineers, and which is put forward to show that the doctors really were desirous of bringing our profession prominently into the field with them in the good work in which both professions and our fellow-citizens generally have so large a stake.

Respectfully submitted.

THOMAS P. ROBERTS.

GEO. H. BROWNE. It is evident, from a cursory perusal of Mr. Roberts' letter, that he has labored to place the medical department of the Board of Health on record rather than himself. Self-denial

*2d. That the Board of Health recommend Councils to order an elaborate and critical survey of the South Side, with a view to exhibit the general topography; also, the depth and area of made ground, with plans for drainage. Also, a survey of the river front of the South Side, from Dam No. 1 to the "Point" bridge, in order to determine the cost of filling out the river bank to the established shore line sufficiently high to be above ordinary floods. A survey and report upon the cost of laying intercepting conduits down both shores of the Monongahela from Dam No. 1 to the "Point," having in view connection of these conduits with the pool above the dam, from which a head of water can be relied upon for properly flushing them.

3d. That the Board of Health request Councils by ordinance to establish the office of Sanitary Surveyor, to be filled by a competent person, to be appointed by the Board of Health, and be subject to their control, whose duty it shall be to supervise and direct the construction and repair of all sewers, and to supervise the construction of all house-drains or pipes connecting with sewers, and without whose permit, advice, supervision or authority no person can or shall be authorized or permitted to make any such connections.

should be applauded only when the object is worthy and the motive originates in ingenuousness. As to the worth, any one can draw the conclusion from the Board's autographic text. If any ordinary reader will take the trouble to examine the report of '78, condemnatory judgment is sure to follow. Is it strange that the report from which I quote should be persistently overlooked when we consider that the absence of all reference proves its indefensible character? Frequent allusions are made to a document which I never knew existed until after my paper was read. My time for the criticism of voluminous documents is very limited; but out of sheer self defense I may be compelled to perform a task for which I have neither the inclination nor leisure, and if forced on me, shall attempt to remodel what is referred to with so much confidence as the model report; and shall do it regardless of whom the animadversions strike.

It is refreshing to hear a modest but brief homily. "Ridicule seldom serves a good object." I am not aware that any one has been exposed to laughter or contemptuous merriment further than grave mathematical deductions would entail, and conclusions the result of such computations seldom excite the risible faculties; although, such logic might engender, in thinking minds, contempt for the men who would set it aside to advocate or ventilate empty opinions. I am a thorough believer in just censure, and regret that it is not now frequently intelligently applied, because it would serve to keep every one within the sphere of his own profession, thoroughly think out the details of any work which he might be called upon to perform, and prevent the trespass of empirics. Ridicule, even, is a poor punishment to inflict on those who undertake to direct, control, or interfere with any engineering work, when they must be thoroughly conscious of their own ignorance on the subject. The man who does so is an insidious enemy to society, and should be reached by some criminal code that would confine the sphere of his usefulness.

The report to which so much reference is made, I am informed, was read before Councils, and that one-half of the members left the room before it was finished; some entered into conversation on other topics, and the balance sought the soothing influence of Morpheus and snorted a requiem. Until distributed with lavish generosity few were aware of its resurrection; and yet Mr. Roberts speaks as if the public waited with longing expectance for its pro-

duction, when in reality, with the exception of a few who may have listened with Spartan resolution sufficiently long to understand what it meant, the public remained in a state of blissful ignorance. Had the report come in my way, as it did not, the chances are that further than glance at the illustrated profiles of death it would have received no further attention, because the perusal of one work of an author is generally sufficient to form an opinion, favorable or unfavorable, of any future work.

If Mr. Roberts reads more carefully he will find that all reference to "systems" of sewerage has been studiously avoided, because so much can be and has been written for and against each system by men whose work, and not opinions, has raised them to eminence in the profession, that I was loath to attempt to dissect, analyze and weigh each opinion or argument, and, from the correct theory extracted, compile a theory entitled "The Only True and Scientific Sewerage System," and then add, parenthetically, that any man advocating such opinions had my unqualified endorsement. Absence of the necessary egotism is the only reason advanceable for the neglect. I simply took Pittsburgh's present system, or rather a small portion of it, and treated it scientifically; and I believe the present mode, if carried out properly, with the additions I suggest, would be sufficiently efficacious.

Finally, Mr. Roberts says that I am "reiterating the opinion of the special committee," which simply means that I am appropriating an idea to which I have no legitimate title or claim. The charge only consists of the plagiarism of one idea. That is fortunate, because I can account satisfactorily for its possession. The charged plagiarized idea is: "Two sewers should be built, one parallel with the Monongahela and one parallel with the Allegheny river, intersecting at laterals;" which simply means that all excrement should be hid from view. My first idea on the subject, though primitive, was borrowed from the cat, and matured by a little reasoning and coupled with a text in Deuteronomy where the children of Israel were instructed to carry a paddle, I came to the inevitable conclusion that "two sewers should be built." By a little reflection you can see how natural such a conclusion arises. Credit where credit is due. I owe the idea to a dumb animal rather than a "special committee" of the higher order of animals. At first view such a confession seems humiliating, but when we consider that the cat's instinct and man's reason are both of Divine origin, the confession loses its humiliation.

MR. DEMPSTER. From the range which the discussion took at the last meeting it would seem that few considered Mr. Browne's paper as an introduction to the subject. The paper was not followed closely. I think when we have papers we should follow them closely in their analyses, and afterwards give such range as would be instructive to the Society. As to the first part, the premises, I think, are uncontradictable. The first point which should receive discussion is the question of ventilation. In the discussion of Mr. Browne's paper he denied the utility of ventilation, but I see on examination of his paper that he admits there are benefits in ventilation. He is correct so far as the *location* of ventilation pipes is concerned, but as to the *exit* I differ from him. I take exception to any system carrying out the gases into the back yards or alleys. The separate sewer system will bear discussion; it has some benefits not perhaps in the other system. I am not prepared to say it is better than the combined system. One point to which I would like to call attention is, that the advocates of that system go on the principle that all the house connections shall be perfect, but they argue against the water carrying system, because the house connections are defective. If, as is asserted, the house connections are bad, would the gas go off by the separate system? I think that whilst there are benefits connected with it from a pecuniary point of view, I am not prepared to advocate it as a whole. We should not take up any one hobby and ride it to death, as it undoubtedly would be; but take all the different systems, bring out all the ideas and construct a system combining all the systems and be best adapted to the wants and necessities of the city.

THE PRESIDENT. I will make a few remarks, although it is not the place of the Chair to enter into the discussions. In regard to Mr. Browne's paper, while I do not work out his formula, I believe the forms of the sewers and the general sizes given to be about right. Mr. Browne calls attention to the great size of the sewers and their bad location, but I think he did not go far enough, for some of the sewers drain large areas and from their small size are liable to overflow. I refer particularly to the Forty-eighth street sewer, built within a few years; it does not carry off the drainage. It is designed to drain the Allegheny Cemetery and the Schenley property (I do not know how many acres, certainly some hundreds) and besides it takes in all the hill district in the range of that water shed. On the night of the Butcher run disaster the sewer was

worthless; the water backed up in the Cemetery to the height of 10 or 12 feet. A pile of 36 inch water pipe was lying below the wall, and when it burst the water carried the pipes to the other side of the street. If it had not been for those pipes the houses would have been swept away and the people drowned. In ordinary rains this sewer fills up. It was a bad mistake in making the sewer too small. I only mention this to show that Mr. Browne ought to be just all around. In regard to the subject of ventilation, so far as Mr. Browne went I agree with him fully, so far as my judgment and reading go. To test the benefit of ventilation, if any one will go into a back yard, where there is a privy vault, he will always find a very bad odor. If you go into the country districts where there are large families of from 12 to 40 people and there are no vaults, etc., and the air has a free sweep to blow through the privies, there is very little offensive smell. The free action of the air carries off the odors and prevents fermentation and the formation of sickening, deadly gases. If a sewer is well ventilated so that the air can pass freely through it, no foul gases will be formed. I know of two cases in this city, in one of which the opening of an old sewer closed for 30 or 40 years, caused poisonous typhus. In another case an old sewer was accidentally opened and violent cases occurred. In another case where the sewerage system was considered perfect 30 years ago as it could be made, the house became foul. No amount of washing or flushing could sweeten the sewer, and cases of diphtheria and gastric fever were developed season after season. The whole system was torn out and the exposed sewer covered with charcoal. On reaching the point where the sewer was ventilated, where the waste from the roof ran in, there was no smell and the sewer was clean. Subsequently the main sewer pipe was carried out through the roof; the traps were all opened into the main sewer pipe, the whole being entirely open and every trap ventilated. The house became pure and sweet and there has been no trace of sickness since. Many experiments were made in Berlin. They tried placing large furnaces at the ends of sewers with fires in them, but the ventilation was not complete; they could not draw the gases through the sewers properly. They still had trouble and established a costly system of gas lights through the streets, to burn sewer gas. It was found that these lights would go out, and the gases floated into the houses. Finally they adopted a system requiring every house to have a pipe run straight out through the roof of the house and connection with

these pipes made by ordinary traps. As soon as this was adopted, no matter which way the wind blew the whole trouble ceased. From all I can learn by reading, I believe that if every sewer were perfectly ventilated and connections in every house carefully trapped, there would very little trouble arise from the sewers. The chief trouble is from confining the gases and allowing them to ferment. A large open lot on Bedford avenue is used as a dumping ground for filth of all kinds. There are at least 500 cart loads of garbage emptied there. People live all around it, and the children make it a play ground, but no one has been contaminated, and the district is free from contagious disease. I venture to say that if you dumped it down into a privy vault where the air could not get at it, and then let the gases ferment and come out, you would have plenty of sickness. I believe that our only salvation lies in plenty of fresh air through the houses and sewers.

Mr. Chas. Davis. The trouble on the South Side is not from defective sewerage or sewer gas, but principally from the want of sewerage and drainage, and from the use of contaminated water.

The district referred to is the Twenty-sixth, Twenty-eighth and Twenty-ninth wards, one of the most thickly built up portions of the whole city. The population is at the rate of about 44,000 to the square mile, a dense population for towns in this country. The level of the district runs from 50 to 80 feet above the river. Formerly the difference was somewhat greater, but street improvements have reduced the irregularities. The back margin of it rises abruptly to an elevation of from 400 to 500 feet above the river. This range is cut up by several ravines, and these discharge their waters into this area. The sewers mentioned were constructed on the valley lines, presumably to take off the surplus water. These sewers are large and have good grades; much better than are ordinarily available. There are openings in abundance along the streets, and I suspect when property holders make use of them the connections to their premises are mere chutes. These sewers are not used to any great extent. There is, however, no reason why these conduits cannot be made to do service in the way of giving better drainage in that locality.

They are built of brick, and as a consequence are not likely to have the objectionable irregularities of the ordinary stone culverts built piece-meal. At one point, near the foot of the Mt. Oliver incline, the want of drainage is particularly noticeable. A large

ravine comes down here. The hillsides are lined with tiers of houses, and the refuse from them is cast out on the walks or passages. In this ravine there are numerous privies and several slaughter houses. In time of storm this rubbish and filth is carried to the head of Twelfth street. Here it is allowed to flow on the surface of the street for two squares to the inlet of the sewer located on Twelfth street, within a stone's throw of the Market house. The blocks in the vicinity are solidly built up with substantial buildings, some of them, (*i. e.*, the blocks,) without any alley-ways or rear entrances. The streets are paved. In this locality there are several wells and one spring. The wells are shallow. The water is seapage from the hills.

The spring has its origin under a horse stable where some 15 or 20 horses are quartered. Above this spring, and across the railroad track, there is a row of frame houses, the waste from which discharges into the space between the railroad and the doors and then disappears, there being no visible outlet for this drain along the track. There can be no doubt that the water is seriously contaminated by the filth on the surface. It should be remembered that the South Side is provided with water drawn from the Monongahela river. There are still a great many wells in use in different parts of the town. Along the river where these go to the gravel, the source is comparatively pure, unless in immediate contact with a cess-pool or house drain. Near the hillside the wells are more or less polluted from the surface filth.

While the town has made ample provision for water supply, it has neglected to take means to have it removed after it is used. In many places, too, the natural drainage of the territory has been interfered with in equalizing the surface for building and street purposes.

This accumulation of filthy water, added to the other unfavorable conditions, has brought about the condition of soil productive of disease. It is not remarkable that in view of this and of the density of the population of this locality, that when any of the zymotic diseases become seated there should be numerous deaths. It is a strange thing that these diseases should spread or be transferred to higher and presumably healthier localities. It is a fact that (considering the number of people in a community) the little settlements about the heads of these gulches always suffer more in proportion from the effects of the so-called filth diseases than those brought in direct contact with them. Mt. Washington has suffered

severely from diphtheria and typhoid fever. We have frequent and severe epidemics where there are no sewers.

Just lately, on the Allegheny river, at the headwaters of Girty's run, along the high slopes, 300 and 400 feet above the river, diphtheria took away a great number, while the low ground near the river, covered with the houses of the populace working in the mill there, escaped entirely.

This summer the high hills and slopes of the valley of Emsworth, just below Pittsburgh, on the Ohio, were visited with a severe type of malarial fever. This has always been regarded as a particularly desirable spot for suburban residences. Here there is no population at the mouth of the run, or any visible contaminating influences.

In both Pittsburgh and Allegheny physicians will tell you of certain types of disease traveling along particular zones of elevation.

There is something in the meteorological phenomena connected with these gulches or ravines affecting the healthfulness of these localities. Professor Jillson has mentioned the subject of meteorological phenomena in connection with the rivers here and the ravines through which they pass as accounting for, in some way, the intensity of local storms (see memoir to Chamber of Commerce, June 3, 1879), and recommends that systematic and simultaneous observations be made (with proper instruments), at different points, with a view of ascertaining the laws regulating these singular movements. It is well known that difference in elevation in ravines makes difference in plant life; plants wither and die in the valleys, while on the high slopes, in spite of the severe frosts and thaws, they thrive.

At Johnstown, a short time ago, the population, mostly children, suffered severely from diphtheria. It did not affect noticeably the overcrowded districts, but was particularly fatal in the best parts of town.

There was no sewerage there, and consequently there could have been no sewer gas. Hon. D. J. Morrell sent circulars to physicians to get their views as to the cause, and their answers were, from want of drainage and from use of well water.

The typhoid fever epidemic at the Reform School in Allegheny, in 1876, was caused by the use of contaminated water drawn from the wells on the premises into which house waste had been allowed to drain—not from sewer air.

Last year malarial fever broke out at Princeton College and a large number of students were prostrated. The cause was attributed to sewer gas from the cess-pool connected with the college building. It was not long after, however, until it was established that this fever prevailed through that section. It was natural that it should be noticeable here, as there were more persons living together at a susceptible age for taking this disease.

A great many of these cases are mere assumptions, and are never properly investigated.

We know but little about sewer air, or sewer gas, as it is called. In London, where it is pent up in 1500 miles of sewers receiving the heterogeneous mass of filth from a teeming population, it has a more potent meaning. The well and spring water in Pittsburgh, generally speaking, is no longer fit for use, and posters should be placed on the pumps and at the springs announcing the fact. This was done in London during the cholera epidemic in 1866. The water pumped by the South Side Water Company, for the section covered by Mr. Browne's paper, is of fair quality, and is not contaminated with sewage, as has been alleged. The influent pipe extends some 400 feet into the river, outside of the influence of drains.

Sewerage and drainage should be provided to take away this supply after it is used, and, also, all liquid filth, and to give good subsoil drainage to the town. As to the other points about the sewerage, they will be mentioned in the remarks for the sewerage of the city.

In Pittsburgh the wants of sewerage are beginning to be severely felt. The city has secured an abundant supply of water by the construction of the Negley's Run Water Works, but in some districts as yet has made no provisions for its prompt removal after use.

In the East End, in many thickly populated parts the waste and liquid refuse is disposed of as formerly, except that the soil is becoming charged with it, and its removal not certain. Municipal policy would dictate that sewerage should be provided to encourage building improvement. East Liberty valley badly needs sewerage. This comprises the largest and one of the most important districts of the city. It contains some 1700 acres, and the best part is some 180 and 300 feet above the river, and portions of it are thickly dotted with suburban residences. A portion of the town of East

Liberty is in this, and without drainage. The district is sharply defined and has its drainage outlet on the Allegheny near Thirty-third street, or through what is known as Skunk Hollow, while the lower and upper ends of the district are thickly populated, and with extensive stretches of paved streets. The intermediate part is rough hillside country, some portions abrupt and rising to a height of 250 and 400 feet above the valley.

The drainage will naturally follow the line of greatest depression to the outlet. This is a natural water course, and runs a part of the way over private property, a part over the Pennsylvania railroad, and part over public streets.

There are a great many points to be settled in regard to the right of way, before the work of construction can be commenced. Then what shall be the nature of this conduit? Shall it be partly open and partly closed or all closed, and with an additional open way to vent the water in time of violent storms? Along the reaches of this run it is evident the valley will sooner or later be filled up to approximate the grade of the railroad for building purposes. We need such territory where it is accessible to the city, for building sites.

This will place the sewer under a very deep fill. On another stretch is the precipitous grounds that will not be altered much in surface for years to come, and from these grounds there will be large volumes of water and great wash. Above this, or in the upper reach of the valley, comes the thicker settled portions again on flat ground, requiring deep drainage and sewerage, the grade for the outlet to the upper end of the valley in some places approximating 50 or 60 feet to the mile.

It is questionable whether a closed conduit throughout, in view of the heavy rain storms in the ravines, and of the liability to stoppage of sewers by wash in unimproved parts, will be satisfactory. To be sure the line of railway gives an open vent for part of the way, as it has a continuous descending grade through the narrower part of the valley.

THE HILL DISTRICT.

The district comprising the greater part of the Thirteenth ward, and having its outlet at Soho, covering some 600 acres, will soon require sewerage. The district having its outlet at the foot of Try street, comprising part of the Fifth, Seventh, Eighth, Eleventh and

the bulk of the Sixth ward, is sharply defined, and is all in the old part of town and compactly built territory. Four Mile and Nine Mile runs, Saw Mill run and Negley's run will be treated as independent districts when the time arrives.

The portion of the improved parts of the city skirting the river will get their drainage generally by the shortest lines to the river, except when the grades of streets running parallel to the river will admit of intercepting sewers near base of hills, so as to get the bulk of sewer discharge as low down on the river as possible. Ultimately, as before remarked, the sewage proper will have to be taken away by intercepting sewers on the shore lines to a point below the city, the storm water, or the bulk of it, discharging into the river by suitable overflows.

CONSTRUCTING SEWERS.

In designing a plan of sewerage for Pittsburgh, provision should be made for carrying a portion of rainfall only, and account should be taken of violent storms of short duration centering about high points and in ravines.

In constructing sewers the main sewers should be laid out in straight lines and with true gradients from point to point, with manholes, lamp holes, and ventilating arrangements at each principal change of line and gradient. The heads of sewers should be provided with proper flushing arrangements. Sewers should not join at right angles; tributary sewers should deliver sewage in direction of main flows. Sewers may be joined without intermediate curves, provided manholes are used to form junctions. Sewers and drains at junctions and curves, should have extra fall to compensate for friction.

Duplicate systems of sewers are not required. Sewers having steep gradients should be built in offsets or steps, at distances of 400 or 500 feet, and provided with flap valves at these points to prevent concentration of sewer air in upper reaches of sewers.

These suggestions are in accordance with the best American practice and are substantially the same, with some emendations relating to detail, as were issued by the Local Government Board (England) in 1865, at the instance of Mr. Robert Rawlinson, Government Engineer, for the use of contractors, and others engaged on sewerage works intended to undergo government inspection.

RECOMMENDATIONS.

As the work is executed, plans on a large scale showing the location, size and depth of sewers, and giving position and arrangement of all fixtures and appurtenances, should be made and filed in the Engineer's office for reference in making house connections and for carrying out extensions.

In building sewers, junction slants in front of each lot should be inserted as the work progresses, and record made of their position on these plans.

Public sewers should not be tapped except under proper municipal regulation.

Drain layers should be licensed to tap public sewers for house connections.

Plumbers should be licensed and give bond for house plumbing.

An inspector of house drainage and plumbing should be appointed.

HOUSE DRAINAGE.

Drains should be effectually trapped at the house line—preferably on the outside of house.

Pipes inside of house should be metal. Soil pipe may be carried through the cellar on hooks in the wall where this is admissible, and should in all cases be extended up full size at the back part of the house to a point above the roof.

Rain water from the roof may be admitted to this pipe by a side opening, provided the capacity of pipe exceeds the capacity of side opening, so as to insure the proper working of pipe as ventilator during storm.

For each tier of water closets or basins a separate stack of soil or waste springing off the main pipe should be provided—these stacks terminating above the roof.

A vent pipe should be taken up along the front of house, either outside or in, from the foot of the soil pipe, so as to complete the circulation of air through the house drains and to vent these drains in case of back pressure from the sewer.

Every house drain should have at least two ventilating pipes—one at the highest point and the other at the lowest.

A small vent pipe should be carried up above the roof or outside the walls for each water closet, sink, bath or basin, and water closets, sinks, baths and basins should have "S" traps.

Safe wastes should be provided having outlet either in the open air through the walls, or in the cellar or basement in an open receptacle.

MR. BROWNE. When Mr. Davis commenced I thought I had something to say, but he has talked so long I have forgotten it all. All this discussion has amounted to about nothing, because it has covered too much ground. All that part of Mr. Davis' paper in connection with poisonous water on the South Side is true; he is simply retracing what has already been gone over and losing time. As to the spread of disease at Mt. Washington, I think the contagion has been carried there by the dwellers of the infected district. If they had spent one-half the money in draining the district that was spent in constructing the large sewers on the South Side, public health would have been different, but as it is it is all wrong.

MR. DEMPSTER. I think it will be necessary to re-open this subject at some future time. Concerning the smallness of the Forty-eighth street sewer, I would just state that it is intersected by water pipe below the crown of the arch about two feet; and then the opening just inside of the cemetery wall became choked by dead leaves from the cemetery and the debris of storms, and this caused a good deal of the stopping up of the sewer. The sewer is large enough to drain the area in ordinary storms, provided there is no stoppage. The difficulty is not in the smallness of the sewer, but in the stopping up. Sometimes from the steep declivity the water comes down so rapidly that it takes time to get out. It is better to make the sewers too small than too large. I have examined the sewers on the South Side, and the difficulty is, the material comes down the hill and there is not sufficient current to take it to the river. It collects in the sewers and then when a flood comes it cannot get out. Several slaughter houses are located in the ravines; the material from them collects in the sewers, decomposes and gives off malaria. On account of the size of the sewers it would be very expensive to flush them; but if they were smaller they could be more rapidly flushed and kept clean. In the long run the expense would not be so great. Mr. Browne is correct in his estimate of these sewers; his calculations are correct as to their capacity. The barricades or pallisades on Twelfth street I think are beneficial, that is, they are beneficial from a pecuniary point of view, in retaining the debris from being washed into the streets, and thus in saving the expense of cleaning it off. I think what we need is discussion

that will be promotive of health—the health of the people. The first consideration is health—death to be avoided; and as a Society, as citizens of Pittsburgh, and in common brotherly interest, we should direct our attention to this matter so as to produce the best results for the welfare of the community. The subject has not received the attention it should receive.

MR. KENT. I think there is no subject more important to the community and to engineers; and I would move that the subject of sewer reform be referred to a committee of three, consisting of Messrs. Browne, Dempster and Davis, who shall receive all papers from the members, collate them, and about next January report such parts of them as they may agree upon; the report not to exceed fifty pages of the Society's proceedings. If the members will present their views and these gentlemen will boil them down, then we will have a paper of benefit to every member and a worthy representative of the Society.

MR. DEMPSTER. That is first rate, but I think our boiling down process would be very slight.

THE PRESIDENT. I will be obliged to declare the motion out of order, as being entirely contrary to the rules of the Society for it to issue papers expressing its opinion *as* a Society. Mr. Kent's plan, while it has in it a germ of good, contains a good deal that is objectionable. It does not conform with the free discussion of the subject. What the Society needs most is that the members should say what they know. Mr. Dempster has promised that in the course of two or three months he would bring up a paper continuing the subject. I agree with an eminent physician that gases have nothing to do with diseases, but fermentation. Typhoid fever could be generated in a dry cellar by an accumulation of all old things, such as shoes covered with mould.

KLOMAN EULOGY.

From proceedings of the Engineers' Society of Western Pennsylvania.

Within the year 1880, but lately closed, the people of this country have been called on to mourn the death of an unusual number of useful men, illustrious by their services, their talents and their worth.

At the December meeting the death of Mr. Andrew Kloman, a valuable, useful and esteemed member of this association, was announced, and brief resolutions referring to his demise and tendering expressions of sympathy to his bereaved family were adopted, and a committee appointed to prepare some suitable memorial and sketch of his life to be entered on our minutes.

It is wise and proper to make mention of useful men, whose lives have closed, in the records of associations to which they belonged, that in future years the ambitious may be incited to emulate them, and that when others occupy our places they may know the memory of such men was esteemed and not forgotten. Without some mention of the subject of this sketch, of the high appreciation of the excellence of his character, the purity of his life and his devotion to the interests of manufacture, our records would be manifestly imperfect, and were no reference made of his many virtues and noble traits, would fail properly to reflect the sentiments of his fellow members who so long knew him in various relations of life.

Mr. Andrew Kloman was born at Treves, Prussia, August 25th, 1827, and received, early in life, the education afforded by the free schools of Prussia, and at the age of twelve went to work under his father in a rolling mill, where he remained until he emigrated to this country in his nineteenth year. He landed in New Orleans on Christmas day, 1845, penniless and almost friendless.

Learning that Pittsburgh offered superior advantages for mechanical skill, he removed here in the spring of 1846, and after undergoing considerable hardship from his want of acquaintance with the English language, he at last obtained employment at the old Novelty Works making scales. This not proving congenial, as he felt within him the fitness for a higher occupation, he obtained a situation at the steel works of Messrs. Singer, Hartman & Co., where his mechanical skill and industrious habits soon gained him favorable recognition, and he was entrusted with the responsible work of finishing and testing steel springs, soon winning the esteem of his employers, and being recognized as the foremost workman of the establishment.

By working early and late and practising the strictest economy he accumulated money enough to start in business for himself, and in 1853, in partnership with his elder brother Anthony, and Mr. Helmbacher, he erected a small forge at Girty's run, where his inventive genius and progressive spirit began to assert themselves, discarding the mere traditions of his trade, and devising original methods and machinery for doing everything required in his business.

The outbreak of the war creating a great demand for axles, he devised a new method of making the pile by bundling one inch square, alternately reversing the direction of their fibres, thereby making so superior an article that the "Kloman" axle was soon widely known and in universal demand.

About 1862 he dissolved this partnership, abandoned this forge, and built the Lower Union Mill. Up to this time he had given personal attention to the mechanical, manufacturing and financial departments of his business, but he now devoted himself especially to the rolling of shapes, and made many improvements in the process, and he here invented the machine for upsetting the ends of eye bars, which had previously been made by forging or welding.

Here he also put up one of the first universal mills operated in this country. In about 1864 the Union Mill was consolidated with the Cyclops Mill, which became known as the Upper Union Mill, where he put up a twenty inch beam mill, this being the first mill built in Pittsburgh that was planned and fitted complete, the rough casting style having been the rule, and here were rolled the first beams made in Pittsburgh.

Here he also erected the first Siemen's regenerative gas heating furnace used in this city, if not the first in the country. He

also invented his machine for straightening and bending beams, channels, etc., cold, and also his reversing universal rolling mill and the disc saw for cutting beams, etc., cold, this being the first practical application of the cold saw, and for all practical purposes he was the inventor of it. He had a wonderful genius for designing rolls adapted for rolling unusual shapes, a conspicuous instance being his rolling the couplings for the arches of the Illinois and St. Louis bridge.

In 1871 he built the No. 1 Lucy Furnace, which at that time and for some considerable time after its erection was the best furnace in the country, making the largest output of any in the United States. Here the system of blowing by volume instead of by pressure was first introduced in Pittsburgh.

In 1872, in connection with others, he formed the Cascade Iron Company for mining ore in the Lake Superior district. This venture resulted most disastrously. If his associates had been able to carry their share of the burden, he would have escaped with a trifling loss, but as he had to bear an excessive share of it, he was left almost penniless. Directly and indirectly this unfortunate venture must have cost him a million of dollars. The delays and complications of this bankruptcy kept him tied down so he could not embark in business again for nearly four years. In this interval he invented the eye bar rolling mill for forming an eye bar direct from the solid pile of iron, or ingot of cast steel, avoiding both the upsetting and welding operations, and having relieved himself of his financial troubles in a way most satisfactory to all concerned, he leased the Superior Mill in Allegheny City and commenced the manufacture of eye bars and structural material, largely devoting himself to steel as a material.

The success of these operations induced him to associate himself in a company for the erection of a Bessemer steel plant at Homestead, and he commenced the building of a large finishing mill for the manufacture of eye bars and other shapes in steel. This he expected to have in operation next fall, when he would have had the best mill in this country. Many other valuable machines, but little known, were either largely or entirely his invention, a self-feeding machine for the manufacture of railroad spikes being one of them. This he took when in a very imperfect shape and developed into a great success.

As an evidence of his good judgment and practical business ability, it may be noted that, with all these mishaps and adverses, he still left his family in good and comfortable circumstances.

The death of Mr. Andrew Kloman occurred at ten o'clock on Sabbath night, December 19th, 1880, at the family residence, Penn avenue. Before the close of a life of unusual activity and energy, he was permitted to witness the rise and wonderful increase of a material industrial interest which has become the distinguishing feature of this country, he having done much by his own mechanical skill and inventive genius to contribute to its development. Mr. Kloman was possessed of a sound judgment and of progressive ideas. The manifold services of this distinguished citizen, artisan and manufacturer, gave him high rank among all engaged in the manufacture of iron and steel, and made his death a loss to the country. He was a man of singular purity, modesty, and simplicity of character. Those who were associated with him during the latter years of his life, and knew of his unremitting devotion to the development of the manufacture of iron and steel, and of his inventive genius in surmounting all difficulties which presented themselves, can best appreciate his worth and noble, manly traits.

There is no department of productive business in which a larger proportion of active brain work is employed than in the invention, building and working of machinery.

The mechanic deals with material substances and mechanical processes that are continually presenting new problems for solution, and are capable of being solved by more than one method, and there is no class of our useful men who, through modesty, offer so little of their experimental and practical knowledge and observant wisdom to the world in printed form.

Mr. Kloman enjoyed a constant and overflowing attachment, a tender and unremitting devotion to his workmen, and they, while at their work and in their homes, entertained warm friendship for him. On the day of the funeral, all work at some of our largest establishments was suspended, and thousands of workmen—who had made the atmosphere of the room in which the casket containing the lifeless body was placed, fragrant with the perfume of flowers—in company with many prominent citizens, followed the remains to the church where the funeral services were performed, and then to their last resting place.

Had the life of Mr. Kloman been spared a few more years, the full triumph of the class of machinery to which he gave so much attention, and to the full and complete development of which he was so greatly devoted, would have been attained. But the fiat of death is inexorable, the silver cord had to be loosed, and the golden bowl broken, and now, when we recall his gentle expression and loving attachments, and hold his memory in respect, and his death in sorrow, we are led to exclaim, "Shall we ever meet him again?"

Ion, the death devoted Greek, when about to yield his life a sacrifice to fate, his Clemanthe asks: "And shall we never see each other?" to which he responds, "I have asked that dreadful question of the hills that look eternal; of the clear streams that flow forever; of the stars, among whose fields of azure my raised spirit hath walked in glory. All were dumb. But now while I gaze upon thy living face I feel that there is something in love that mantles through its beauty, that cannot wholly perish:—we *shall* meet again, Clemanthe."

Respectfully submitted.

JAMES PARK, JR.,
JAMES HEMPHILL, } *Committee.*

SOME WASTES OF HEAT.

By Wm. Metcalf, C. E.

[Read October 18, 1881.]

It is not the purpose of this paper to go into a discussion of the theoretical quantity of heat to be obtained from a pound of coal, as compared to the actual amount obtained. All this is to be found laid down in the books over and over again to stimulate engineers to try and stop the enormous loss shown, and many of the ablest men of the world are working at this fruitful problem. A far more odious and obvious comparison is intended; one that is ever present to us, in the shape of huge volumes of smoke, and bright, but expressive bonfires, that are pouring out of the tops of our furnace stacks, day and night. It is proposed to show, by figures obtained from actual working data, how much money is annually thrown away in Allegheny county, by throwing money into our furnaces in the shape of coal, to be sent, wasted, out of the tops of stacks in the shape of dirty, useless smoke, and red, and far more expensive flames.

FURNACE DATA.

The data of old style furnaces are obtained from some of our ablest and most reliable iron manufacturers. The data of the new style furnaces are obtained from personal experience, and from a few iron makers who have tried and who are adopting the new style furnaces. By the old style furnace is meant the ordinary reverberatory furnace, and by the new style is meant any good regenerative gas furnace. The data of quantities of iron made are taken from the paper of Wm. P. Shinn on "Statistics of Pittsburgh Manufac-

tures," read before the American Institute of Mining Engineers in May, 1879.

The price of fuel is assumed as the probable average cost of the fuel laid down at the furnace. If the price should be too high or too low in any case, the correction can easily be made for any particular mill, by parties interested. In stating that 40 bushels of coal are used in puddling a ton of iron, I am well aware that many iron men say puddling can be done, and is done, with 30 bushels per ton; but on the other hand some of the very best and most experienced men say that 40 bushels is nearer the actual figure of the amount used. Again, I have placed the quantity of slack used in a gas furnace at 20 bushels per ton of iron, which is the highest quantity I have ever known to be used, while I do know that 15 bushels is nearer the actual consumption, and there are furnaces now building which I believe will produce regularly a ton of muck iron with 10 bushels of slack. For the gas furnaces these figures include the consumption of fuel, and wages of gas makers from Saturday noon until Monday morning, during which time the furnaces are kept hot, and are idle. For heating, I have used equal quantities of coal for one style and of slack for the other, as given by iron men, although I am satisfied that this is an error in favor of the reverberatory system; but not having measured these quantities myself, I take the data of those who have made the comparison by actual measurement. I would call your attention particularly to the enormous difference by loss in oxidation, or scaling.

Difference in Cost.

We have, then, for puddling—

Old style—Coal, 40 bushels, at 6 cts	$2.40
New " —Slack, 20 " " 3 cts	.60
Difference in fuel	$1.80
Deduct for gas making	.42
Saving in fuel in puddling 1 ton	$1.38

Re-Heating.

Old style—Coal, 18 bushels, at 6 cts	$1.08
New " —Slack, 18 " " 3 cts	.54
Difference in fuel	$ .54
Deduct for gas making	.21
Saving in fuel per ton	$ .33

Loss by Oxidation—Scaling.

Old style, 10 per cent	224	lbs. per ton.
New " 6 "	134.4	" "
Saving in iron by scaling	89.6	" "

This gives us—

Difference per ton of muck bar	$1.38
" " in fuel for heating	.33
" " in scaling for heating	2.24
Total saving in one ton of bar iron, once re-heated	$3.95

Mr. Shinn's paper gives the quantity of rolled iron produced in Allegheny county in 1878 as 252,083 tons of 2240 lbs. Assuming this, and multiplying by the figures just given, we have—

Loss in puddling,	252,083 @	$1.38	$347,874.54
" heating,	252,083 @	.33	83,187.39
" scaling,	252,083 @	2.24	564,665.92
Total loss			$995,727.85

An iron maker who was consulted in the matter, estimated that 25 per cent. of the iron made is twice heated. Assuming for this quantity one-third of the above difference in scaling as a probably safe estimate, and all of the difference in fuel, we have: 74.6 loss for scaling+.33 fuel=$1.07.6 as the total loss in this operation. Twenty-five per cent. of 252,083=63,020; in round numbers, 63,020 ×$1.07.6=$67,869.52. Adding the above total, $995,727.85, we have $1,063,537.37 as the total annual price paid in Allegheny county for the bonfires we keep at the tops of our furnace stacks. At first sight it may seem incorrect to assume the loss in scaling at 2½c. per pound; you will understand, of course, that there is no way of getting at exact selling prices, and it is probable, when we consider how much iron goes into special forms, that the "card" is about the average price. Again, the selling price is proper, because the manufacturer loses the material that scales away, less only the value of tap cinder. The workman loses the wages of this amount, because it would increase neither his hours nor his labor perceptibly, if the additional yield were made. And finally, the manufacturer loses the profit of this amount, as its sale and distribution would not increase his expense account.

These figures are enormous and fairly open to criticism, yet I know of one instance where a careful record of several gas furnaces which cost from $10,000 to $15,000 each, showed that each furnace paid for itself every year; and of another case where a furnace which is not as well arranged as it ought to be, and which cost less than $6,000, showed a daily saving of $56, or about $15,000 a year; and of another case where the gas system was only partially in use, where there was a saving in the total annual fuel bills, per ton of product, of 46 per cent.

Several questions will naturally occur, such as—What is the wear and tear? How much fix does the new style furnace consume? What is the cost of a gas furnace? Will not slack increase in price? What sort of heat do you get? Is the work as good? etc. As to wear and tear, I believe it to be much less in a gas furnace than in a reverberatory.

A careful record of one run of a puddling furnace when 552 tons of muck were produced, showed that the total cost of rebuilding, including castings, bricks, fire clay and all wages, amounted to 32c. per ton. For heating I have no figures, but I know of one furnace that ran for six years, alternately heating iron and steel, before the crown gave out, and then only about one-third of it had to be replaced, and during those six years I do not think fifty dollars, all told, was spent for little repairs, such as re-lining the doors.

In puddling strong pig containing not over two per cent. of silicon, about 350 pounds of fix, wet weight, are used per ton of muck.

Gas furnaces, including producers, but not including royalties, can be built for about the same cost per ton of capacity as ordinary reverberatory furnaces. Slack might increase in price if all of the mills of Pittsburgh used only slack; but it is not likely that much increase would occur, because it is difficult for the river mines to dispose of a large part of their slack; and again, run of mine coal works so much stronger than slack in the producer, that it can be used at about the same cost per ton of yield of furnace.

The gas heat is uniform, continuous, and very soft; iron comes from the furnace thoroughly heated through without being burnt, so that the usual exclamation of the men is, "it is as soft as butter!" The work done in the gas furnace is, on the whole, much better than that done in a reverberatory furnace, because the heat is more uniform, and it requires the grossest carelessness to burn iron in a gas furnace.

Besides, the work is so very much easier for the men that they naturally do much better work, because their labor is not so exhausting and they take more interest in it. This is a point of no little importance, for it is easy to obtain a very high quality of finish at no increase of cost; and when men are contented the troubles of the "bosses" are very light. No account has been taken of the wages question, because with the above stupendous figures it is a question not worth considering in this connection; but it is a fact that men can do from 10 to 20 per cent. more work on a gas furnace than on a reverberatory; they can do it easier, and they can do it better.

Therefore, the new style gives the working man a chance to make money too, without interfering with the present lists; and the gas system requires as many hands as the other, if not more, therefore its introduction need cause no opposition.

It has been suggested that the publication of this paper, if the statements given are all correct, might injure Pittsburgh by inducing outside manufacturers to adopt this gas system. The fact is, shrewd manufacturers from parts of the country as widely separated as New England and the Pacific Slope, have visited Pittsburgh repeatedly; have examined this system carefully; have adopted it extensively; have written back that they were delighted with it, and were pushing their changes rapidly. Under these circumstances it is barely possible that it is worth our while to look to our laurels.

In conclusion, I wish to say that I do not want to be understood as claiming to be, in the works with which I am connected, in advance of the rest of the world. We still use some of the wasteful style of furnaces, and a complete emancipation from old ways is always difficult to accomplish, but we are making as rapid a development of the use of regenerative furnaces as we can.

One field for the regenerative gas system is still unoccupied; I refer to the firing of steam boilers. Some Germans have recently shown that by gas firing, 90 per cent. of the fuel will evaporate double the quantity of water in a given boiler. This simply means that any concern can double its steam producing capacity at a very trifling cost, and with no increase of plant.

A battery of boilers is now being fitted in this city with regenerative gas fires, and if the results claimed by the Germans are realized, the facts will be laid before the Society at an early day.

In the meantime the subject commends itself to every one who is interested in economy and cleanliness.

The economical side of the question has been shown; the cleanly side is accomplished of necessity; first in the greater cleanliness of the works, and second from a reduction of the smoke nuisance; for it is well understood by all who know how to work a gas furnace, that a smoky stack is a sure sign of a furnace that is in bad order, therefore smoke from a gas furnace is always inexcusable.

DISCUSSION.

VICE PRESIDENT RODD, IN THE CHAIR. I think Mr. Metcalf could not have chosen a subject of more interest to Pittsburghers generally, and one which concerns them more intimately. I hope it will receive the full discussion which it merits.

MR. PARKIN. As the President has pretty well covered the ground, I can add but little. I have operated gas furnaces for about ten years, using them for almost everything, such as annealing at a low red heat. We have used them for heating steel and for melting; the highest imaginable heat is necessary to melt steel. Recently we have adapted them to welding cast steel. Of course there are many objections made to the gas furnace on the ground that it does not work satisfactorily, most all of which are due to faulty construction. If the gas furnace be properly proportioned and constructed, it will give satisfaction. A great many objections are from the fact that furnaces are not properly proportioned. Where properly proportioned they are simple, and give an uniform heat. The furnaces are perfectly clear. There are no unsightly objects around, such as are ordinarily seen about reverberatory furnaces.

MR. KIRK. For information, I would like to ask, if there are so many advantages for iron men, is there a corresponding advantage for household purposes? Can the same principles be adapted to household use?

THE PRESIDENT. I think that in not many years from now the subject will be better understood. The principles can be adapted to household furnaces almost as cheap as coal gas, even at the present price of gas. One of the important differences between the new and old furnaces is in the melting of steel. In the old style it requires 150 bushels of coke for one ton of steel. Only 15 bushels of slack are needed with the gas furnace. There is a saving in puddling of two-thirds, in melting about nine-tenths, and in heating not so much.

Mr. Hunt. I would like to ask if there is any difficulty from explosions?

The President. We have never found any at all. I don't know that we could make one explode. In the gas made, only from 20 to 25 per cent. is combustible material, the balance is nitrogen and carbonic acid. Some very simple results have been obtained already. When Dr. Siemens was in this country, in 1876, he examined the natural gas furnaces then in use. One mistake made in the beginning was the attempt to superheat the gas. Dr. Siemens said that he had tried in every way the regenerative system on hydro-carbon gas. By using the regenerative system only on the air, and bringing the gas on cold, then the most intense heat could be obtained from hydro-carbon gases with the greatest economy. I am certain that some one will take up this household problem. It would not cost more than the present use of coal.

Mr. Hunt. I agree thoroughly with the speaker. I believe the gas furnace should supersede the old reverberatory furnace. They do not cost very much more, especially since the Siemens patents have run out. Until the men got used to them they were not as successful as they should have been, requiring more skilled help to run them, but of late they have been worked well by ordinary furnace men. I believe it is going to be proved that the old style furnaces are out of date. Another thing—in other countries different kinds of fuel are used in gas furnaces. In Sweden they are using sawdust, and make from it a quality of gas superior to ours, in not having sulphur in it. Frequent explosions occur in the Swedish gas furnaces using a blast of air in the producers. We have no trouble of the kind in this country. Most of our gas producers use only the chimney draft, and do not use the direct blast. A great many gas furnaces are being used. There are several other forms than the one described, several of which have given considerable success in use.

Mr. Kirk. I would like to know if Mr. Metcalf will undertake to give us, at the next meeting, the dimensions or plan of some general apparatus for individual isolated houses?

The President. I refer the gentleman to some one who works in that line. I referred to the gas generative system, which I believe will soon come into use.

Mr. Miller. I think the subject is nowhere near to being exhausted; some gentlemen have more to say. I therefore move that the subject be continued until the next meeting.

THE PRESIDENT. Will Mr. Dempster favor us with a few remarks?

MR. A. DEMPSTER. I was unfortunately absent from the last meeting, and not having received a copy of the paper, I have not seen or heard a word on the subject.

MR. W. S. JARBOE. A great many new inventions are coming up in this line; I understand Mr. Reese has one. Many forms of gas furnaces are now in operation—Wilson's and a number of others. Pittsburgh will be likely to lose her laurels if we do not take active steps. I saw a furnace in Boston which burned about 3500 pounds of slack and about 20 per cent. bituminous coal. The New York Heating Company has a gas furnace of 150 horse power. The Brush Electric Light Company uses this kind.

THE PRESIDENT. Will you give us a section and description of that furnace?

MR. JARBOE. I did intend to give it this evening, but the data did not arrive. It would not cost over $130 per boiler.

MR. J. L. GILL, JR. There is a little matter which came under my notice. An acquaintance was making an investigation for a manufacturer in the iron business, to decide certain questions connected with the establishment of new works. I made a number of visits with him, and in the course of the investigation we found a considerable difference in the amount of coal consumed in the different establishments in producing one ton of iron. In one case the amount consumed was 50 per cent. more than the minimum; another 100 per cent.; another 150 per cent. more. In the concern consuming the largest amount, the very best coal was used. The one using the minimum amount, used only slack and nut coal. The greatest difference, of course, was in the construction of the furnaces. In giving this statement I simply give in general the information obtained. I am not at liberty to give the exact data.

THE PRESIDENT. I would like to inquire whether the figures were taken from the books or not.

MR. GILL. They were, in every instance.

MR. JACOB REESE. The rate would be very low in producing the heavy grades of iron, but the finer iron would take a good deal more fuel. I cannot conceive of such great differences in puddling in Pittsburgh. I have never known a person to give figures over 42 bushels per ton in puddling. Scarcely over 40 bushels is the average for puddling.

MR. GILL. In the one consuming the largest amount of fuel we have the books to show for it; I saw them myself.

THE PRESIDENT. One of the largest manufacturers in Pittsburgh told me that he had the matter under consideration for a long time, and that there was a loss of 20 per cent. in fuel in one ton of pig iron, while in reducing pig to wrought the loss was from 12 to 15 per cent. In regard to puddling I will say, that with our furnace, in making over 6000 tons of iron, the highest consumption we could get out of it was 20 bushels of slack to one ton of muck iron.

MR. GILL. I would like to state that Mr. Metcalf was not puddling iron at the time these observations were made.

THE PRESIDENT. In regard to workingmen, we have never had any serious trouble. After the men have once worked on a gas furnace you cannot drive them away. There must be some one person who thoroughly understands the principle of the furnace and every detail. It only takes a very little teaching and a good man will go along very straight.

MR. —— ——. The great trouble has been about the royalty on these furnaces, amounting to from $10,000 to $15,000. I understand that a number of patents have run out. The Chester Furnaces, at Thurlow, are now putting up a furnace on the Siemens patent, now run out, without paying for it.

ELECTRICITY;

WHAT IT IS, AND WHAT MAY BE EXPECTED OF IT.

By Jacob Reese.

[Read November 15, 1881.]

In the consideration of this subject it is not my purpose to review the steps of discovery and development of electrical phenomena, but the object of this paper is an effort to explain what electricity is; and having done this, to deduce some reasonable conclusions as to what may be expected of it. And while I am profoundly sensible of the importance of the subject, and the difficulties attending its consideration, still with humble boldness I present this paper and ask for it a serious and careful consideration, hoping that the discussion and investigation resulting therefrom may add to our knowledge of physical science.

It is now a well established fact that matter, *per se*, is inert, and that its energy is derived from the physical forces; therefore, all chemical and physical phenomena observed in the universe are caused by and due to the operations of the physical forces, and matter, of whatever state or condition it may be in, is but the vehicle through or by which the physical forces operate to produce the phenomena.

There are but two physical forces, *i. e.*, the force of attraction and the force of caloric. The force of attraction is inherent in the matter, and tends to draw the particles together and hold them in a state of rest. The force of caloric accompanies the matter, and tends to push the particles outward into a state of activity.

The force of attraction being inherent, it abides in the matter continuously and can neither be increased nor diminished; it, however, is present in different elementary bodies in different degrees, and in compound bodies relative to the elements of which they are composed.

The force of caloric is mobile, and is capable of moving from one portion of matter to another; yet under certain conditions a portion of caloric is occluded in the matter by the force of attraction. That portion of caloric which is occluded (known by the misnomer, latent heat), I shall call *static caloric*, and that portion which is in motion, *dynamic caloric*.

The force of attraction, as I have said, tends to draw the particles of matter together and hold them in a state of rest; but as this force is inherent, the degree of power thus exerted is in an inverse ratio to the distance of the particles from each other. The effective force so exerted is always balanced by an equivalent amount of the force of caloric, and that modicum so engaged in balancing the effective force of attraction is static, because occluded in that work.

In solid or fluid bodies, where the molecules are held in a local or near relation to each other, the amount of static caloric will be in direct proportion to the effective force of attraction, but in gaseous bodies the static caloric is in an inverse ratio to the effective force of attraction; hence the amount of static caloric present in solid and fluid bodies will be greatest when the molecules are nearest each other, and greatest in gaseous bodies when the molecules are furthest apart.

Caloric, whether static or dynamic, is not phenomenal; therefore the phenomena of light, temperature, incandescence, luminosity, heat, cold and motion, as well as all other phenomena, are due to the movement of matter caused by the physical forces. Thus we find that *temperature is a phenomenal measure of molecular velocity*, as we consider weight to be the measure of matter.

An increase of temperature denotes an increased molecular velocity, and this in solid and liquid bodies unlocks a portion of the static caloric and converts it into dynamic caloric, while an increased temperature of gases occludes additional caloric, thus converting dynamic into static caloric; and a reduction of molecular activity reverses this action. From this we see that a change of temperature either converts static to dynamic or dynamic to static caloric.

Thus we find that the amount of static caloric which a body possesses is in direct relation to its temperature; but, as I have already explained, temperature is a phenomenal indication of molecular velocity, and as increased velocity separates the molecules to a greater distance, which reduces the effective force of attraction and unlocks a portion of caloric, it will be seen that the separation of the molecules from any other cause will have the same effect. I desire now to explain a second method by which the molecules are separated and static caloric is changed to dynamic caloric.

It is not definitely known how much static caloric is occluded in either of the elementary bodies, but it is believed that hydrogen possesses the greatest amount and oxygen the least. Now if we take a molecule of hydrogen containing two atoms, and under proper conditions interpose these atoms between 16 atoms of oxygen (one molecule), the phenomenon of combustion is exhibited, and a molecule of water is formed containing 18 atoms; and if one pound of hydrogen is thus consumed, the atoms of hydrogen are separated from each other to such a distance by the interposing atoms of oxygen as to unlock 34,662 units C. of static, and convert it into dynamic caloric. And if we thus bring a molecule of carbon containing 12 atoms in contact with a molecule of oxygen of 16 atoms, combustion ensues and a molecule of carbonic oxide of 28 atoms is formed, and if we then present another molecule of oxygen, combustion again takes place, and a molecule of carbonic acid, containing 44 atoms, is produced. Now, in the combustion of one pound of carbon in this manner, when the carbon is converted into carbonic oxide (CO), 2473 units C. of static is converted into dynamic caloric; and when this CO is converted into carbonic acid (CO_2), 5607 additional units C. are unlocked. Thus by the combustion of one pound of carbon to CO_2 8080 units C. of static caloric are changed to dynamic caloric.

When caloric is thus unlocked from its occlusion it escapes with great velocity until an equilibrium is attained, and in doing so it pushes the particles of matter out of its path. In solid bodies this produces such a high degree of molecular movement as to exhibit the phenomena of incandescence and luminosity, and in liquids increased mobility, while in gases the molecular activity may be so great as to produce the phenomena of sound and light; and the more rapidly combustion takes place the greater will be the volume and velocity of dynamic caloric escaping therefrom; consequently

with a slow combustion, the phenomena produced by dynamic caloric will be different from those exhibited at a high degree.

Combustion, as I have before shown, is merely the oxidation of the material; nothing is *consumed* nor annihilated, and the phenomena vary with the velocity of oxidation. Now, if we take one pound of zinc and place it in the acid cell of an electric battery, the oxygen of the acid attacks the zinc and oxide of zinc is formed. In this operation the Zn molecule containing 65 atoms is united with one molecule of oxygen of 16 atoms, forming a molecule of oxide of zinc (ZnO) of 81 atoms; and owing to the comparatively small number of oxygen atoms interposed between the 65 atoms of zinc, only 1301 units C. of static caloric are unlocked to the pound of zinc, and the velocity of oxidation is so low, and the insulation of the vessel so perfect, that the dynamic caloric is caused to flow outward through the copper wire.

Electricity.—What is it? Why, it is dynamic caloric. Now let us take this oxide of zinc (ZnO) and place it with charcoal in a reducing apparatus which stands on an insulated table; the apparatus is then heated, the carbon vaporizes, and this vapor of carbon (C) robs the oxide of zinc (ZnO) of its oxygen, leaving metallic zinc (Zn) and carbonic oxide (CO). Now, for every pound of zinc so formed, 1301 units C. of static caloric are transferred from the charcoal to the zinc and occluded in it. Hence we find that the 1301 units C. of caloric which we took out of the zinc, and which we call electricity, is nothing else but the 1301 units of static caloric which was contained in the charcoal and from it set free by oxidation and transferred to the zinc in the smelting process. Let us follow this matter a little further. Charcoal is made by burning wood under such conditions as eliminate the water and hydrogen and leave the carbon as a residuum which we call charcoal. Thus we find that the caloric contained in the charcoal, transferred from the charcoal to the zinc, and from it developed into what we call electricity, was previously embodied in the wood; and if we study the laws of vegetation, we find that the atmosphere being charged with carbonic acid (CO_2), the leaves of plants, shrubs and trees, breathing, take in the CO_2, the sun rays decompose the CO_2, set free the oxygen and supply the necessary amount of caloric for the condensed state of the carbon. Thus we find that the force which we term electricity, developed from the oxidation of zinc, or any other matter, by oxidation, primarily comes from the sun rays.

Coal is generally supposed to be of vegetable origin, and the caloric occluded in it is derived from the same source as that embodied in charcoal. Now when we burn coal under a steam boiler, the carbon and hydrogen are oxidized, and the static caloric set free. A portion of this caloric passes through the shell or tubes of the boilers, and increases the molecular velocity of the water; increased activity of the molecules tends to separate them to a greater distance from each other. When the molecular velocity of the water acquires the degree indicated by a temperature of 212 degrees F., the water passes from the fluid to the gaseous state, and in doing so, expands to 1696 times its bulk. Now if the steam so developed be confined under a pressure of 105 pounds to the square inch, the water will not vaporize until a molecular velocity is attained indicated by a temperature of 312 F., (Spon's Engineering, D2, page 418), and then the expansion is only 253 times its bulk. By using this steam in a steam engine, the caloric in the steam tends to push the molecules of which it is composed into an ultimate expansion of 1696 times the bulk of the water from which it was generated, and this force acts upon the piston and does the work. Thus we see that the steam engine is driven by the same force which produces the phenomena accredited to electricity.

I have already shown that in what we term combustion not a particle of the ponderable matter is annihilated. Combustion is but a phenomenon resulting from a rearrangement of the particles, and so it is with the imponderable physical force caloric; it is not consumed when light and heat are produced, nor converted into power, as we are sometimes told. But whatever the phenomena produced, the aggregate amount of static and dynamic caloric is always and ever the same.

If we consider the Ritter-Plant-Faure-Battery which is mentioned as storing electricity, we find that the phenomena exhibited by the use of this apparatus are produced by the same factor. The battery is composed of two sheets of lead, which are covered with a layer of minium ($Pb_3 O_4$). The sheets are laid one upon the other with an intervening layer of felt. The pack is then rolled up in a spiral form and placed in a vessel containing acidulated water. One of the plates is connected with the positive, and the other plate with the negative pole of a battery or generator.

When the current of electricity enters the battery, the $Pb_3 O_4$ on the positive plate is reduced to $_3Pb$, and the oxygen so set free,

attacks the $Pb_3 O_4$ on the negative plate, and oxidizes it to $Pb O_2$. In this chemical action, caloric is occluded in the Pb and unlocked in the $Pb O_2$, but a much greater amount of caloric is locked up than is unlocked, although the amount of oxygen used in both cases is precisely the same, which has been fully explained in the oxidation of carbon.

Now, after the battery has been thus charged and the wires disengaged, the chemical action ceases for want of the reducing agent (*dynamic caloric*), and the apparatus may be held at rest, or transported to any distance required. When it is desired to utilize the force thus stored, the poles are changed by grounding the positive wire, and attaching the other to the conduit through which the electricity is to flow. The chemical action is thus reversed, and the $Pb O_2$ is reduced to $Pb_3 O_4$, the oxygen thus set free attacks the Pb on the other plate, oxidizing it to $Pb_3 O_4$, thus unlocking all the caloric which was occluded by the first action. In a battery of this kind weighing 75 pounds, we are informed by Sir William Thompson, that one million foot pounds of force may be stored, and again set free for use.

Thus we find the principle upon which the Faure battery is formed is not new, and the prime factor producing the phenomena is the same as has been shown to have caused all other phenomena referred to, and indeed the principle is the same as now employed by the author in the basic dephosphorizing process, *i. e.*, caloric is occluded in phosphorus by smelting in a blast furnace, and unlocked in the converter, for the purpose of securing the fluidity of the metal during treatment. The difference being, that one is done by non-luminous, while the other is by luminous combustion.

If we consider the phenomenon of light, we find that it is due to the same force. As before stated, when we oxidize carbon, or hydrogen, as in the rapid combustion of wood, oil or coal, the escaping caloric flies off with such great speed as to cause the molecules in the circumambient medium to assume a velocity which exhibits luminosity. Thus the light produced by burning candles, oil, gas, wood and coal, is caused by the same prime factor, dynamic caloric.

The force of caloric is imponderable and invisible, and is only known by its effects. We do know that it is occluded in metals and other material, because we can unlock it and set it free, or we can transfer it from one body to another, and by measuring its effects

we can determine its quantity. We know that it prefers to travel over one vehicle more than another, and by this knowledge we are able to insulate it, and thus conduct it in any direction desired. The materials through which it passes with the greatest freedom are called conductors, and the materials which most retard its passage, non-conductors, but these terms must be taken in a comparative sense only, as in fact there are no absolute non-conductors of dynamic caloric, or of what we call electricity.

The dynamo-electric generator simply draws the dynamic caloric from the air or earth, or both, and confines it in an insulated path. Now if that path be a No. 10 wire, the conduit may be sufficient to permit the caloric to pass without increasing the molecular velocity of the metal to an appreciable degree, but if we cut the No. 10 wire and insert a piece of No. 40 platinum wire in the path, the amount of caloric flowing through the No. 10 wire cannot pass through the No. 40 wire, and the resistance so caused, increases the molecular velocity of the No. 40 wire to such a degree as to exhibit the phenomenon of incandescence, and this is the incandescent electric light. And if we consider the carbon light, we find that the current of caloric in passing from one pencil to the other, produces a molecular velocity of luminosity in the adjoining atmosphere, and in addition, a portion of the carbon is consumed, which sets free an additional amount of caloric, at a very high velocity; hence the intensity of the carbon electric light is largely due to the dynamic caloric unlocked from the pencils, and thus we find that the electric light produced by either method, is due to the action of dynamic caloric.

Taking this theory, based upon physical science, and the facts which we know pertaining to electricity, I conceive that caloric exists in two conditions. *Static caloric* is what we call *latent heat*, and *dynamic caloric* is what we call *electricity*. Therefore what we may expect of it (electricity) is merely a matter of economy in the development and utilization of dynamic caloric; in other words, can we unlock static caloric by non-luminous combustion, and thus develop *dynamic caloric as a first power* more economically per foot pound than we now do, or can hereafter do, by luminous combustion? Second, can we utilize water and wind for the production of *dynamic caloric as a first power?* Third, can we utilize the differential tension of dynamic caloric in the earth and the atmosphere as *a first power?* Fourth, will it pay to use luminous combustion as a first power to generate dynamic caloric as *a second power?*

WHAT WE MAY EXPECT OF IT.

Let us take the steam engine and see what we are now doing by luminous combustion. Good Pittsburgh coal contains 87 per cent. of carbon, 5 per cent. of hydrogen, 2 per cent. of oxygen and 6 per cent. of ash; we therefore have in one pound of such coal:

$\frac{8080\times9}{5}=\frac{14,544\times87}{100}=12,653$ units in carbon.

$\frac{34,662\times9}{5}=\frac{62,391\times5}{100}=3119$ units in hydrogen.

15,772 units in coal.

15,772×772*=12,175,984 foot pounds of energy is occluded in the static caloric contained in one pound of such coal.

A horse power is estimated as capable of raising 33,000 pounds one foot high per minute, and for this reason it is termed 33,000 foot pounds per minute. So we have 33,000×60=1,980,000 foot pounds per hour, as a horse power.

The best class of *compound condensing* engines,† with all the modern improvements, require 1,828 pounds of coal per 1 H. P. per hour. Thus we have—

12,175,984×1,828	22,257,699
Foot pounds in one H. P	1,980,000
Foot pounds lost per H. P	20,277,699
Per cent. utilized per H. P	8.94
" lost per H. P	91.06
	100.00

In the ordinary practice of stationary non-condensing engines, from three to four pounds of coal are required per horse power per hour. Now, taking the best of this class at 3 pounds, we have—

12,175,984×3=	36,527,952
One H. P	1,980,000
Loss per H. P	34,547,952
Per cent. utilized per H. P	5.42
" lost per H. P	94.58
	100.00

* Dr. Joule—foot pounds in one unit.

† American Engineer, Vol. II, No. 10, page 182.

From these facts it may be assumed, that after making due allowance for variable qualities of the coal, the steam engine process, as at present practised, will not utilize more than from 5 to 10 per cent. of the energy contained in the fuel used. It will thus be seen that the process of converting static to dynamic caloric by luminous combustion, by means of the steam engine, is an exceedingly wasteful and costly method, and leaves much room for economy.

Taking an ordinary grade of petroleum as consisting of 13 per cent. hydrogen, 78 carbon, 6 oxygen, 3 nitrogen and ash, we have as its energy in foot pounds, per pound of oil—

$$\left.\begin{array}{l} \dfrac{62{,}391\times 13}{100} = 8{,}110 \text{ H.} \\ \\ \dfrac{14{,}544\times 78}{100} = 11{,}344 \text{ C.} \end{array}\right\} \quad 19{,}454 \text{ units.}$$

$19{,}454\times 772 = 15{,}018{,}488$ foot pounds. Thus, while our best coal contains twelve million, the petroleum contains fifteen million foot pounds of occluded energy in each pound, which is equal to 118,000,000 foot pounds, or 60 horse power for one hour, from one gallon of such oil.

At present electricity is generated by two methods, and both of these are *second powers.* Metals are smelted by luminous combustion as a first power, and then oxidized by non-luminous combustion as a *second power*, and coal is consumed by luminous combustion, by which steam is generated as a first power, to drive a dynamo-generator whereby electricity is obtained as a *second power.* Now of the two methods, the latter is much the cheaper, and as I have shown that the best compound condensing engines only utilize 8.94, and a fair average single cylinder condensing engine only utilizes 5.42 per cent. of the energy of the fuel consumed, and as at the best not over 70 per cent. of the foot pounds obtained from the engine can be utilized as electricity, from which we must deduct loss by friction, etc., it will be readily seen that not more than 5 per cent. of the energy of the fuel can be developed by the dynamo-generator as electricity by the present method.

The great want of the present age is a process by which the static caloric of carbon or a hydro-carbon may be set free by non-luminous combustion; or, in other words, a process by which coal

or oil may be oxidized at a low degree, within an insulated vessel; if this can be accomplished (and I can see no reason why we should not look for such invention), we would be able to produce from twelve to fifteen million foot pounds of energy (electricity) from one pound of petroleum, or from ten to twelve million foot pounds from one pound of good coal, which would be a saving of from 90 to 95 per cent. of present cost, and leave the steam engine for historical remembrance.

Electricity may be generated by water or wind power to great advantage, and conveyed to a distance for motive power. The practicability of generating electricity at Niagara by which to propel trains to New York and return may be considered as almost settled, and I conceive a second invention of importance which is now needed is an apparatus by which the rising and falling tides may be utilized for driving dynamo machines, by which electricity may be generated for lighting the coast cities, and it is not unreasonable to expect that such an apparatus will soon be provided; and in such an event gas companies would suffer.

It is a well known fact among electricians that the volume and tension of electricity vary, both in the earth and in the atmosphere, at different sections of the earth's surface, and I conceive that we may yet find means of utilizing this differential tension of electricity; indeed, it is reported that during a recent storm the wires of an ocean cable were grounded at both ends, and a sufficient current for all practical purposes flowed from the European to the American continent, with all batteries removed, showing that the tension was so much greater in Europe as to cause the electricity to flow through the copper cable to this side in preference to passing through the earth or the sea. It is also said that during an east-going storm it was found impossible to work the telegraph lines between New York and Buffalo, but on taking off the batteries at both ends and looping the ends of the wire in the air, that a constant current of electricity passed from Buffalo to New York, and the line was kept in constant use in that direction without any battery connection until the storm abated. Now how far, or to what advantage we may be able to utilize this differential tension of electricity in the earth and the air, we cannot now say; but I think that we may justly look for valuable developments in this direction.

If, as I verily believe, a process will soon be discovered by which dynamic caloric can be produced by the oxidation of petro-

leum with non-luminous combustion in an insulated chamber, as we now oxidize zinc, electricity will then be obtained from so small a weight, and at such a low cost, as to ensure aerial navigation beyond a doubt. Not with balloons and their cumbrous inflations, but with machines capable of carrying the load, and traveling by displacement of the air at high velocities. Therefore we may expect that aerial navigation will be developed in the near future to be one of the greatest enterprises of the world.

And lastly, will it pay to use luminous combustion as a first power for generating dynamic caloric for use as a second power, as is now practised?

At the University of Pennsylvania, in Philadelphia, gas is consumed in an Otto gas engine, which drives a Gramme generator, and the lecture room is lighted with electricity; and I am informed that the light is both better *and cheaper* than when they used the gas in the ordinary gas burners. Hence we may expect to see gas consumed to advantage for producing electric lights.

Considering the difficulties of transmitting steam power to a considerable distance, and the comparative great cost of running small engines, it is more than likely that electricity as at present generated will be found to be economical for driving small motors.

Having thus endeavored to explain what electricity is, and the laws which govern the occlusion of static caloric, and the development of dynamic caloric (electricity), in conclusion, I call the attention of the inventors of the age to the great need of a process for oxidizing coal or oil at a low degree, within an insulated vessel. With such an invention, electricity would be obtained at such a low cost that it would be used exclusively to light and heat our houses, to smelt, refine and manipulate our metals, to propel our cars, wagons, carriages and ships, cook our food, and drive all machinery requiring motive power.

DESCRIPTION OF COFFER DAM USED AT DAVIS ISLAND DAM,

IN THE

CONSTRUCTION OF THE NAVIGABLE PASS. SEASON OF 1881.

By Wm. Martin, C. E.

[Read December 20, 1881.]

The navigable pass is that portion of the dam over which sill the greatest depth of water is always obtained, and which extends out into the river at right angles to the lock, a distance of 558.89 feet.

The coffer dam extends out from the river lock wall a distance of 612 feet and parallel to the current of the river a distance of 237 feet, enclosing an area of $3\frac{1}{3}$ acres. The area thus enclosed, besides giving the necessary space required for the dam, gave ample room for all the machinery of construction.

A coffer dam may be described as a water-tight wall constructed around the site of any work for the purpose of laying, dry, the foundation of pier, wall, or any other structure that may be intended, by pumping out the water from the area thus enclosed. The methods used in different works vary according to the uses intended and the facility for procuring the materials of construction.

The preliminary steps taken in the one which is the subject of this paper, was to drive two rows of oak piles 15 inches in diameter and 20 feet long, to an average depth of 8 feet, at a distance of 15 feet 8 inches transversely and 21 feet longitudinally between centres, between which the framework was constructed, the piles serving to hold the framework in position until the puddling was placed.

The framework consisted of three rows of stringers placed 12 feet 4 inches apart, between which the sheeting was placed vertically, driven into the gravel 2 feet. The joints of the sheeting were covered with a 1 inch strip 6 inches wide, to prevent leakage of the puddling. (The placing of which to be described hereafter.) At the top of the sheeting are spiked two string pieces 2 inches by 10 inches on each side of the sheeting, to form a bearing for the joist on which the deck was laid, also to bind the tops of sheeting together.

The stringers were placed at the centres of pressure of rectangles of equal pressure, and were united together by a scarf joint with an iron rod passing through the entire width of the coffer dam with a nut on each end.

One set of workmen assembled the stringers both in respect to height and width, and were followed by another set who drove the sheeting, and still by another who trimmed the tops of them, and put on the 2x10 inch string pieces, the joists, and the deck.

The most interesting part of the work was the placing of the puddling, and to which this paper chiefly refers.

The total length of the coffer dam was 1437 feet; 379 feet of it was puddled by material taken from the coffer dam used in the construction of the river wall; the remaining 1058 feet was puddled by material obtained on Davis Island.

The method employed in puddling the coffer dams of the land and river walls, was to deliver the material in cars by a tramway from the point of excavation to the river, where it was loaded into boats, from thence transported across the river where it was delivered into the framework of the coffer dam by hand labor, and having to be watered to settle it.

The method employed in puddling the coffer dam of the navigable pass was by forcing the material by means of a centrifugal pump through a pipe, from Davis Island to the coffer dam, the plant of which consists of boiler, engine, piston pump, centrifugal pump, delivery pipe, and the necessary steam and water connections.

The pump, which was of the ordinary centrifugal type, was located on Davis Island, a distance of 900 feet from the coffer dam. Alongside and beneath the pump was a tank for mixing the puddle material, 8 feet in diameter and 4 feet deep, sunk to a depth sufficient to secure fall for a water culvert from the river.

The piston pump was connected to the delivery pipe by a wye connection, and was used for clearing the delivery pipe, for priming the centrifugal pump and keeping the sand from the packing, (as described hereafter), and for furnishing water for the agitator hose and the steam boiler.

The puddle material, which consisted of loam and sand, was obtained within a radius of 100 feet from the pump by loosening up the soil with a plow and delivering it in close proximity to the tank by horse scrapers, and from thence delivered to the tank by shovels, where it was mixed with water from the culvert and kept agitated by water from hose pipe in the hands of the workmen, to prevent the mixture from settling in the bottom of the tank.

The puddle material so mixed was taken up by the feed pipe of the centrifugal pump, and forced through the delivery pipe to the coffer dam, the distance to which was constantly increasing, owing to the advancement of the completed work.

The delivery pipe was laid from the centrifugal pump along the bottom of the river, and thence rose to about 1 foot above the top of the coffer dam by an easy ascent, avoiding any sharp angles.

On the pipe at the pump a pressure gauge was used for the purpose of detecting any stoppages in the pump or delivery pipe whereby the free working of the pump might be impaired. These were frequently caused by the puddle material being fed too thick. When the gauge indicated a stoppage the operator slackened the speed of the centrifugal, and opened the valve in the wye connection to the piston pump. A stream of clear water was then thrown from the piston pump through the delivery pipe at high pressure, and the pipe was cleared. The check valve in the delivery pipe between the wye connection and the centrifugal pump prevented a back flow into the centrifugal pump.

On the bottom end of the feed pipe was a screen with meshes of one square inch to prevent stones, roots, or any material which might prevent the free working of the pump from being taken up by the feed pipe. Above the screen, and in the same casing, was placed a foot valve for the purpose of holding the priming.

One of the principal difficulties experienced in working the pump was the rapid wearing of all the parts of the centrifugal pump with which the sand came in contact. The casing, which was originally three-eighths of an inch thick, wore through in about ten days

This was replaced by a casing one inch thick, which performed all the work required. The stuffing box wore rapidly until the following device was applied: A screw was cut in the chamber in the opposite direction to the motion of the shaft. A pipe was put in back of the packing and connected with the piston pump. Water was forced through this around the shaft, and being under a greater pressure than the centrifugal pump, prevented the puddle material from getting into the stuffing box. Water so applied performed a double duty, acting as a lubricator, and preventing the shaft from heating.

At the discharge end of the delivery pipe the puddle material was deposited in the framework of the coffer dam and flowed off for a distance of a few hundred feet, depositing in a hard and solid mass. Being delivered in a liquid form, it penetrated every crack and crevice in the framework and required no ramming or watering to settle it. A point noticed in the mass was, that the puddle material, composed of loam and sand in its original state as on Davis Island, was completely separated. The loam being the lighter body, was kept longer in suspension and settled on top of the sand.

There was delivered into the coffer dam by the above described process 5784 cubic yards of puddle material in 23 days time, equal to 251.4 cubic yards per ten hours working time, or 25.14 cubic yards per hour. The cost of this was as follows:

Cost of pump	$ 145 00
Repairs, fittings, &c	382 25
Pipe	364 09
Fuel	38 35
Cost of labor, erecting machinery, making excavations for tank and water culvert feeding the centrifugal pump, &c	2847 07
Total	$3776 76

A comparison of the above figures with the cost of the puddling of the river wall coffer dam, which was procured from Davis Island as described, and the cross section of which was the same, shows as follows:

	Length.	Total Cost.	Cost per Lin. Ft.
Coffer dam of river wall	1,165 ft.	$6,628 37	$5 69
" " " navigable pass	1,085 "	3,776 76	3 48

During the construction of the river wall coffer dam 12½ cents per hour was paid to laborers, and 22½ cents per hour to the

mechanics, while during the construction of the navigable pass coffer dam, laborers received from 17½ to 20 cents per hour, and mechanics from 25 to 27½ cents per hour.

This makes the above statement still more favorable to the method of pumping.

The dimensions of the principal parts of the machinery were as follows:

Tubular steam boiler	36 in. diam., 16 ft. long.
Steam engine	10 in. diam., cyl. 10 in. stroke.
Piston pump	steam cyl. 12 in. diam., cyl. 18 in. " water cyl. 6½ in. diam., cyl. 18 in. "
Centrifugal pump	8 in. diam. of discharge.
Delivery pipe	4 in. diam.
Clearing "	2½ "
Priming "	1½ "
Lubricator pipe	1 "
Agitator hose	1½ "
Steam pipe to engine	2½ "
Steam pipe to piston pump	2 "
Band wheel on engine shaft	4 ft. 6 "
Pulley on centrifugal pump shaft	10 "
Width of driving belt	10 inches.

The pressures carried were as follows:

Steam boiler pressure	100 lbs. per square in.
Gauge on piston pump	70 " " " "
" " delivery pipe	35 " " " "

The plant of the above described process, as originally designed, was very much simplified during the progress of the work, much that was complicated having been omitted for more simple devices.

The cost of placing the puddling was thereby considerably increased.

It is believed that with the improved machinery, as described above, the puddle material can be placed at one-half the figure given.

ABSORPTION OF METALLIC OXIDES BY PLANTS.

By Prof. F. C. Phillips, of the Western University.

[Read February 21, 1882.]

The question, how far the vital processes of plants are influenced by the various mineral compounds presented by the soil to their roots, has long been under discussion in physiological botany, but further than to establish the fact that the presence of certain compounds in soil tends to increase the nutritious elements and promote the growth of particular vegetables, little has been done towards a complete solution of the problem.

It is well known that potash tends to increase the quantity of starch, that silica strengthens the stems of the grasses, that oxide of iron is essential to the production of leaf-green, that phosphates increase the fertility of the soil for cereals, but even as regards these constant elements of every soil, very little can be positively asserted of the precise influence of any one, in the economy of the plant.

Concerning the part played by the rarer elements, cæsium, rabidium, copper, nickel, manganese, zinc and barium in the assimilation of carbon, nitrogen, and the functions of nutrition, and whether they are beneficial or injurious, nothing whatever is known, although modern refinements in chemical methods have led to their frequent detection both in soil and in plants. That so important a problem should have remained almost wholly unsolved, must be attributed chiefly to the very great difficulties which are met in any experimental investigation, but also to the fact that the few investi-

gations published have been carried out, in most cases, for the purpose of proving that vegetation had been injured by metallic compounds traceable to a metallurgical works, and with the especial purpose of founding a claim for damages, rather than to solve a scientific problem. The study of the influence of metallic compounds on plants has recently acquired great practical importance from the fact that many manufacturing processes, more especially those employed in the smelting of lead and copper, and arsenical ores of various metals, have given rise to a gradual impregnation of the soil with such metals, and to the consequent poisoning of vegetation and animals.

In almost all cases where furnaces for the treatment of such ores have been erected, there has followed a serious injury to vegetation, caused by the metallic vapors and dust escaping from the flues. While the lawsuits instituted to recover damages have brought forward many interesting facts as to the extent of vaporization of metals, the necessity and difficulties of providing proper means for condensing the noxious fumes, the evidence has seldom furnished any definite information as to the more general question at issue.

The possibility of injury to plants from such sources has been denied under an assumption that plants, like animals, possess a certain discriminating power, and that they are able to select and take up, through their roots, such elements of the soil as are nutritious, and to reject all else; a view which is very commonly accepted, and has been held by high authorities.

With the very much less complete condensing apparatus in use in former times, the injury caused by such establishments was far greater than at present, but even at smelting works where the most improved machinery is in use, it is often difficult to prevent the escape of large quantities of poisonous mineral compounds, which in the shape of dust may be carried many hundred yards and scattered with injurious effects upon vegetation.

As early as the year 1668 mention is made of the injury to pastures, caused by lead fume, by Joseph Glanvil, who published a description in the "Philosophical Transactions" of the smelting of lead ores in the Mendip Hills.

The author says: "There is a flight in the smoak, which, falling upon the grass, poysons those cattel that eat it. They find the taste of it upon their lips to be sweet, when the smoak chances to fly in

their faces. Brought home and laid in their houses, it kills rats and mice.

"If this flight mix with the water in which the oar is washed, and be carried away into a streame, it hath poysoned such cattel as have drunk of it after a current of three miles."

Richard Watson, in his "Chemical Essays," published in 1799, calls attention to the saving to be effected, and the protection afforded to pastures, by the use of long horizontal chimneys for the condensation of lead fume, in Derbyshire.

"But so difficult is it," says this author, "to wean artizans from their ancient ways, that I question whether any of them would ever have adopted the plan they approved, if an horizontal chimney which was built in Middleton Dale to protect pastures from the smoke of the furnace, had not given them full proof of the practicability of saving the sublimate of lead which is lost in the ordinary method of smelting."

Among more recent cases, the following, cited by Taylor, in his "Treatise on Poisons," (3d American edition, p. 424,) is of interest:

"It was alleged on the part of the plaintiff that a large number of sheep and cattle had been destroyed by fumes of lead escaping from a chimney on the defendant's works. The case involved this curious point, namely: admitting the sheep and cattle have been destroyed by lead, whether the lead was deposited on the herbage from the defendant's chimney, or taken up by the plants from the soil, and incorporated with their tissues. The condensing arrangements at the lead works were found to be almost absolutely complete, and there was not the slightest appearance of a deposit of white lead on the herbage. But it was found that the herbage was impregnated with lead, and that seeds sown in the leaden soil, brought for this purpose to London, produced plants containing lead. The soil had derived the lead from ancient mineral workings."

Dr. Wilson, (Edinb. Monthly Journal of Medicine, 1852,) in a case somewhat similar to that cited by Taylor, of cattle poisoning by lead, found the herbage to contain the metal, and that beans grown upon a portion of the soil were impregnated in the same manner.

These results seem to point very clearly to the possibility of the absorption of lead by the roots of plants.

An exhaustive investigation into the action of copper and zinc on vegetation has been made by Dr. Freytag, of the Agricultural Laboratory in Bonn, and the results published in an official report upon

the injury alleged to have been caused by the smelting furnaces of Mansfield. In the neighborhood of Mansfield furnaces have been in operation for several centuries, and the soil in many places has in consequence become greatly deteriorated as regards its fertility, being charged with as much as ten pounds of oxide of copper and twenty-four pounds of oxide of zinc to the ton of earth. In order to test the influence of these metals upon the nutritive qualities of the crops, Freytag made comparative analyses of clover and grass grown in the neighborhood of the smelting furnaces, and of similar plants grown five miles distant, but under as nearly as possible the same conditions of temperature, moisture and manuring. The plants from the neighborhood of the furnaces differed in the following points from those grown at a distance :

1. They contained in their ashes varying quantities of the oxides of copper and zinc, as much as 0.2 per cent. oxide of copper, and 0.36 per cent. oxide of zinc.

2. There was a larger percentage of sulphuric acid, attributed by Freytag to the fact that the copper and zinc occur in the soil as sulphates.

3. The proportion of nitrogenous bodies was greater by 25-30 per cent. (2 per cent. of the dried plant). As regards the assimilation of nitrogen, therefore, the metallic sulphates were apparently beneficial.

Very interesting experiments have been made by Freytag upon the capacity of plants to absorb solutions of metallic salts.

Beans, peas and other seeds were allowed to germinate in a solution containing nutritious matters, and after maturing were transferred to solutions containing arsenious acid, the sulphates of iron, cobalt, nickel, zinc and copper.

The result was that a solution containing 1-80 per cent. arsenious acid proved fatal, as was also the case with 1-25 per cent. sulphate of cobalt, 1-15 per cent. sulphate of nickel, 1.50 per cent. sulphate of zinc, 1-5 per cent. sulphate of iron.

No injurious effects were produced by more dilute solutions, the plants continuing to thrive until the poisonous limit of concentration was reached, when they rapidly withered and died.

In all cases there were found in their tissues small quantities of the respective metals in whose solutions they had been grown.

Freytag says: "I have found that plants growing in solutions of metallic salts are killed when the concentration reaches a certain

degree, which is in all cases below 1 per cent. of the solution, and this statement applies equally to those salts which are essential to plant life. If we accept this as equally true of plants growing upon soil, it follows that the moisture of the soil must contain very small traces of mineral salts in solution, and by experiment it has been shown that the watery extract of a soil which is charged with salts of the heavy metals, always contains less than the fatal dose of such metals."

Freytag thus sums up :

"It has been fully demonstrated that plants are not capable of selecting from the substances presented to their roots; that they are, on the contrary, compelled to take up all matters alike, which are in a form fitted for absorption, but that matters insoluble in the moisture of the soil are never taken up in sufficient quantities to endanger the life of the plant."

Freytag claims as his own, the theory of non-discrimination of plants, but Liebig, in his Agricultural Chemistry, (4th English edition, page 66,) states that "all substances in solution in a soil are absorbed by the roots of plants, exactly as a sponge imbibes a liquid and all that it contains, without selection."

Freytag has detected zinc and copper in the leaves of oaks and birch trees in the Mansfield district, and in a series of experiments it was found that zinc added to soil in the form of carbonate is absorbed by rye, wheat and maize, and is deposited in the leaves, stems and seeds. Many plants growing near zinc mines absorb considerable quantities of oxide of zinc, and in two well known cases new varieties are considered to have been produced by soil containing zinc, one a shepherd's purse (Thlaspi Alpestre, variety Calaminaris), the other a violet (Viola Tricolor, variety Calaminaris).

The latter plant is considered by some authorities to be a distinct species. The ash of the leaves of this violet contains 13 per cent. oxide of zinc. Both of these plants are confined to localities where zinc is an element of the soil, and the zinc seems therefore to be an essential constituent.

Among the strongly poisonous metals zinc appears, according to the investigations published, to be the most rapidly absorbed by plants. It is of singular interest, however, that experiments conducted in the botanical garden at Erlangen, have led to a negative

result, as regards the possibility of its absorption, contradicting, therefore, those obtained by Freytag.

In the report of the Commissioner of Agriculture, (Washington, 1875) some experiments are described upon the action of Paris green on vegetation. Peas were sown in soil containing varying quantity of Paris green. No injurious effects were produced where the quantities of the arsenical compound was less than 900 pounds per acre of soil. When present in larger quantity, the plants were feeble and were smaller in proportion as the arsenic was increased. With 1½ tons of Paris green to the acre the seeds failed to germinate. The plants were tested for arsenic but were found to have not absorbed even traces of the metal recognizable by Marsh's test.

These results involve, therefore, a direct contradiction of Freytag's theories, both as regards the non-absorption of the metal, and as regards the vital processes of the plant. According to Heckel (Comptes Rendus, vol. LXXX, p. 1172), water containing 3-100 per cent. of arsenious acid prevents the germination of seeds and destroys the embryo plant.

For the purpose of throwing some light on this difficult problem of the influence of metallic oxides upon plant life, a series of experiments was carried out during the last spring, in the greenhouse of the Allegheny park, by the kind permission of the superintendent of the parks, Mr. William Hamilton.

The object of these experiments was to determine, firstly, whether any injurious effects are produced upon plants by being grown in soil impregnated with certain metallic oxides; secondly, whether plants in a perfectly healthy state will absorb such oxides through their roots. In the early spring the greenhouse was filled with very young plants, in a vigorous condition of growth, which were being reared for the purpose of supplying the park in the summer. The plants selected were geraniums, coleas, ageratum, achyranthes and pansies. This selection was made, not with reference to any special peculiarities of the plants, but for the reason that there were thousands of other plants of the same kind, and all equally advanced in growth, on the tables of the greenhouse, which afforded an opportunity for a close comparison of those grown upon poisoned soil with others grown under normal conditions.

The compounds used were the carbonates of zinc, copper and lead, and as an arsenical compound, arsenate of lime. These compounds are almost absolutely insoluble in pure water.

The method of setting the plants was that commonly employed by gardeners in transplanting. Young plants, with their roots as nearly as possible intact, were placed in flower pots, and soil previously mixed with a weighed quantity of the metallic compound was poured in and pressed down around the roots. The first series included ageratums, which were grown in soil containing ½ per cent. white lead.

The second series consisted of geraniums, which were grown in soil containing ½ per cent. carbonate of zinc.

The third series included achyranthes. The soil supplied to them contained ½ per cent. carbonate of copper.

The fourth series were coleas, which were grown in soil containing ½ per cent. arsenate of lime.

The fifth series included coleas, grown in soil containing ½ per cent. arsenate of lime.

The sixth series were pansies, grown in soil containing ½ per cent. carbonate of zinc.

All these plants enjoyed the usual careful greenhouse nursing, and as regards temperature, moisture and fertility of the soil, the conditions were absolutely the same as in the case of the other plants, excepting the poisonous influence to which their roots were exposed.

The progress of each plant was watched and a record kept. On the 10th of June, eleven weeks after the commencement of the experiments, the plants were cut off above the roots, and those of each series subjected to analysis, with the following results :

The ageratums, grown in leaden soil, matured and produced flowers as early as the most advanced of those grown in ordinary soil. Their roots were very abundant and healthy, the only noticeable effect of the lead being that the leaves were of a yellowish hue. The analysis showed that lead had been absorbed in small quantities.

In the second series geraniums were reared in soil impregnated with carbonate of zinc. The plants were in every respect normal, bore flowers, and produced abundant roots.

The analysis showed considerable quantities of zinc.

In the third series achyranthes were grown in soil containing carbonate of copper. The effect of the copper was not visible in the plants at first, as they continued to grow rapidly, and were normal in color. But in maturing, the bright leaves became darkened. It was found that the copper had killed the original roots, and totally

arrested the development of new ones. The plants had apparently been nourished from the air alone. Very small quantities of copper were found in their ashes.

The most strongly marked results were produced in the case of the arsenic. In the fourth series coleus were grown in soil containing $\frac{1}{2}$ per cent. of arsenate of lime. The effects of the poison were visible in a few days, the plants languishing and producing but few leaves. In the course of two weeks all were dead.

In the fifth series, coleus were reared in soil containing $\frac{1}{4}$ per cent. of arsenate of lime. The plants were feeble from the first, produced but few leaves, which were normal in color. Although they endured with greatly diminished vitality, no increase in growth took place, and the stems were not strong enough to remain erect. In all cases the arsenic had totally destroyed the roots. Traces of arsenic were found in the analysis.

In the sixth series, pansies, grown in soil containing carbonate of zinc, produced abundance of roots and continued healthy. Analysis proved the presence of zinc in considerable quantities.

In view of conflicting statements of authorities, further experiments on a large scale, and extended to a wider range of plants, grown under varying conditions, would be needed to establish any general laws in regard to the absorption and influence of metallic poisons contained in soil upon vegetation. The discovery of these laws would probably lead to the discovery of methods for the prevention of such influences, so far as they are of a dangerous character.

From the experiments detailed above it seems safe to conclude, however,—

1. That healthy plants, grown under favorable conditions, may absorb through their roots small quantities of lead, zinc, copper and arsenic.

2. That lead and zinc may enter the tissues in this way without causing any disturbance in the growth, nutrition, and functions of the plant.

3. That the compounds of copper and arsenic exert a distinctly poisonous influence, tending, when present in larger quantity, to check the formation of roots, and either killing the plant or so far reducing its vitality as to interfere with nutrition and growth.

In the case of the heavy metals, copper, zinc, arsenic and lead, it seems to be probable that their oxides may under certain circum-

stances become deposited in the tissues of the plant. As to the manner in which this takes place, authorities differ.

It is supposed by Freytag and others that plants absorb all soluble matters indiscriminately, through their numberless rootlets, and that the absorption of poisonous metals causes no disturbance until a certain degree of concentration is reached, when the plant rapidly withers and dies. That plants are therefore spared the sufferings of chronic poisoning, but are very susceptible to acute poisoning, which is invariably fatal. While it is held by others that plants absorb only such elements as are essential and nutritious, refusing to take up what is poisonous or innutritious. Metallic compounds found in the analyses are therefore to be traced to atmospheric deposits adhering externally.

The theory of Freytag seems to have the weight of facts in its favor, and if it is possible that crops may become charged in this way with poisonous elements of the soil, it becomes a matter of the highest importance that wherever there is danger of such impregnation the most efficient means be employed for its aversion: for soil once impregnated with copper, lead and zinc, may year after year bear crops poisoned in the same manner.

THE SLIDE RULE.

By Edwin Thacher, C. E.

[Read March 21, 1882.]

The slide rule is no new theme. Some varieties of it have been known and used for the past two hundred years. It has never received the attention to which it is justly entitled, nor are its wonderful labor saving properties generally understood.

It is equally well adapted to the wants of the engineer, architect, actuary, mechanic and business man, and is within the comprehension of all. The American people are not slow usually to avail themselves of the benefits afforded by labor saving appliances, and lead the world in the invention and production of implements to overcome the wear and tear of manual labor. Like efforts have not been made to relieve the mind of its drudgery, and to overcome the exhausting effects of close application to tedious arithmetical processes. It is a matter of some surprise to those having a knowledge of the use and capabilities of the slide rule, that it has not been employed to a much greater extent. By its aid the most irksome arithmetical and trigonometrical operations become a pleasant recreation. Its combinations are few and simple and easily understood, but its application to all ordinary business transactions is unlimited. The farmer accustomed to his modern reaper or mower would dislike to again rely on the sickle, cradle, or scythe, and the traveler accustomed to lightning express trains would dislike to again rely on canals and stage coaches; likewise, and in no less a degree,

would the calculator accustomed to the unexampled rapidity and ease in calculation afforded by the slide rule, dislike to dispense with the power thus placed in his hands and rely on the unaided pencil.

Whatever specialty the engineer has chosen he will find ample opportunity for its use.

The bridge engineer will find it useful in finding the moments and shears in plate girders; the strains and sections in trusses; the bearing and shearing values of pins and rivets; the thickness of bearing plates; the length of tie plates; and estimates of quantities, cost, etc.

The railway engineer will find it useful in the mensuration of lines, areas, surfaces and solids; in the production of estimates of work done and material furnished; in solving trigonometrical and other formulæ; in making and applying tables, etc.

The mechanical engineer will find it useful in problems involving any of the mechanical powers; in finding the pitch, number of teeth and diameter of toothed wheels; in designing the parts and ascertaining the power of engines and other machinery, etc.

The hydraulic engineer will find it useful in ascertaining the supply of water from rainfall; the force, velocity and pressure of water; the power of water wheels; the duty of pumping engines, and the solution of most of the formulæ relating to hydraulics and hydro-dynamics.

The scientist will find it useful in the conversion of thermometric scales; in finding the specific gravity of bodies; in problems relating to uniform or accelerated motion; force of wind; velocity of sound; vibration of pendulums, centrifugal force, etc.

The mechanic will find it useful in estimating the contents of round and square timber; finding feet board measure; angles; diagonals, etc.

The business man will find it useful in problems of simple and compound interest; discount and fellowship; extending pay rolls; pro-rating accounts; assessing taxes; gauging casks; estimating the weight of metals and other material; for the exchange of money; conversion of foreign and domestic weights and measures, etc.; and all will find it useful in miscellaneous applications of multiplication, division, proportion, fractions, roots and powers, and as a check on ordinary methods of calculation.

The slide rule offers a mechanical solution of problems due to the principle of logarithms; that the product of two numbers corresponds to the sum of their logarithms, the quotient of two numbers to the difference of their logarithms, and the power of any number to the product of the logarithm of the number and the index of its power.

A logarithmic scale is one representing the logarithms of all numbers, or one on which the distance of any number from the commencement of the scale corresponds to the decimal part of its logarithm.

The ordinary slide rule consists of a piece of boxwood provided with a longitudinal groove into which a slide is fitted, the slide being of boxwood or brass and having its upper surface in the same plane as that of the rule. On the slide are laid off two logarithmic lines, each consisting of two complete logarithmic scales. On the rule, in contact with the slide, are two additional lines. The line above the slide is similar in all respects to those on the slide. The line below the slide has a scale of double length, or a single scale completes the line; this latter is the line of roots. The four lines of the rule are usually designated by the letters A, B, C and D, but for convenience in comparing different constructions as well as in applying the rules and directions hereafter given, the lines on the slide being alike and dependent in movement will be known as A, the upper similar line as B, and the lower line, or line of roots, as C.

In the use of this instrument numeration is the first requirement and should be fully understood before proceeding further. Figures from 1 to 10 mark the principal divisions on the scale. Each of the spaces between the prime divisions are divided into ten parts, of slightly varying lengths, called tenths. These may again be divided into hundredths and thousandths, the number of divisions depending on the length of the scale, but it is not desirable to make the divisions much if any smaller than one-fortieth of an inch, as it will be found to confuse rather than to assist the reading. Each class of divisions represents some decimal part of the preceding class, always one-tenth, except for the last or smallest divisions into which any space is divided, and these usually represent either one-tenth or two-tenths of the next preceding class.

Values intermediate between two consecutive divisions of the last order are estimated by the eye, and by a little practice this can be

readily done with great exactness. The values of the divisions on the scales are all arbitrary, the values set upon them depending upon the question considered, and are then determined thus: 468 on the scale may mean 46800., 4680., 468, 46.8, 4.68, .468, etc., but the values of any intermediate divisions are governed by the prime division; for instance, on the ordinary rule between figures 2 and 3, if 2 means 20, the first tenth following means 21. If 2 means 200, the first tenth following means 210, and so on for all parts of the scale.

The value of any result can generally be determined by mere inspection, but for the benefit of such cases as are not readily determined, a general rule will be given hereafter.

It may be supposed by some that as the slide rule is indebted to logarithms for its power, that a knowledge of logarithms is essential to its intelligent manipulation, but such is not the case. The numbers and divisions on the scale are not logarithms but occupy the place of logarithms, and are read in the same way as any other decimal scale.

With ordinary scales of equal parts the sliding of one scale upon another would give addition and subtraction. On the slide rule similar movements give multiplication and division. It may sometimes be interesting to follow out the manner in which different movements produce the desired result, but for all practical purposes the rules following will be found sufficient. These rules are general, being applicable to multiplication, division, proportion and powers; are simple and easily remembered, and are believed to be new.

The answer to any problem that can be solved by the slide rule, will be regarded as the fourth term of a proportion and the statement will contain the remaining terms.

If $a : b : : c : d$, then $\frac{bc}{a}=d$, in which the denominator is the first term, and the numerator contains the second and third. These terms may have any value, but the form of the expression must remain unchanged. If $a=1$, we have multiplication. If b or $c=1$, we have division, and if a, b and c have a value different from 1, we have ordinary proportion.

The expressions $\frac{ax}{b}$, $\frac{ax^2}{b}$, $\frac{ax}{b^2}$, and $\frac{ax^2}{b^2}$, when the slide is direct, and $\frac{ab}{x}$, $\frac{ab^2}{x}$, $\frac{ab}{x^2}$, and $\frac{ab^2}{x^2}$, when the slide is reversed, are readily solved by the slide rule. a and b are used in setting the rule. They

may have any value, but the rule must be set as often as their value is changed. x is not used in setting the rule, and may have any number of values without resetting. This is a valuable feature, for a very large percentage of calculations consist of series having a, single variable.

Bearing in mind that the slide is known as A, the similar fixed line as B, and the line of roots as C, the following is a general rule for setting and reading:

Rule I.—Set a, on line A, to b, on line $\left\{\begin{matrix}\text{B if 1st power}\\ \text{C if 2d "}\end{matrix}\right\}$ then opposite x, on line $\left\{\begin{matrix}\text{B if 1st power}\\ \text{C if 2d "}\end{matrix}\right\}$ read the answer on line A. This rule applies whether the slide be direct with the variable in the numerator, or the slide be reversed with the variable in the denominator, and is sufficient to work any example that it is often desired to work with the slide rule.

The expressions $\sqrt{\frac{bx}{a}} = \frac{\sqrt{b}\times\sqrt{x}}{\sqrt{a}}$ and $\sqrt{\frac{b^2x}{a}} = \frac{b\sqrt{x}}{\sqrt{a}}$ when the slide is direct, and $\sqrt{\frac{ab}{x}} = \frac{\sqrt{a}\times\sqrt{b}}{\sqrt{x}}$ and $\sqrt{\frac{ab^2}{x}} = \frac{b\sqrt{a}}{\sqrt{x}}$ when the slide is reversed, are also within the capacity of the instrument and are solved by the following general rule:

Rule II.—Set a, on line A, to b, on line $\left\{\begin{matrix}\text{(B if 1st power)}\\ \text{(C if 2d "}\end{matrix}\right\}$. Then opposite x, on line A, read the answer on line C.

As all radical quantities have two roots, one for an even and one for an odd number of places in the quantity under the sign, and the wrong one is liable to be taken, rule II must be used with caution. It is safer, in general, to first find the value under the sign and then find the root by a second operation. For cases in which the value of the radical is known sufficiently near to obviate this objection, as is often the case, the rule can be used with great advantage. The rapid solution of problems in cube root requires an instrument in which single and triple lines can be brought into direct comparison, but the cube root of any number may be found with the ordinary rule by the following special process: To find $\sqrt[3]{a}$, reverse the slide, set a, on line A, to 1, on line C; then look for the number on line A that is opposite the same number on line C; this number is the cube root sought. As there are three points on the lines that satisfy this condition, it is necessary to know approximately the first figure or the wrong root is liable to be taken.

POSITION OF DECIMAL POINT.

To find the position of the decimal point, or the true value of any result, the following directions are to be observed :

First. In the statement of any problem in multiplication, division, proportion, or powers, it must be observed that the numerator is always composed of two factors, and the denominator of one quantity.

Second. The number of places in quantities of the first degree are taken plus a number equal to the number of places of whole numbers, and minus a number equal to the number of ciphers in decimals; thus, $2146=+4$, $214.6=+3$, $21.46=+2$, $2.146=+1$, $.2146=0$, $.02146=-1$, $.002146=-2$, etc.

The number of places in quantities of the second degree are taken as follows :

All quantities on the line of roots C to the left of the centre of the rule, or between 1 and $\sqrt{10}$, are taken plus a number equal to double the number of places of whole numbers, less 1, and minus a number equal to double the number of ciphers in decimals, less 1; thus, $(217.0)^2=+5$, $(21.7)^2=+3$, $(2.17)^2=+1$, $(.217)^2=-1$, $(.0217)^2=-3$, $(.00217)^2=-5$.

All quantities on the line of roots C to the right of the centre of the rule, or between $1/\sqrt{10}$ and the end of the scale, are taken plus a number equal to double the number of places of whole numbers, and minus a number equal to double the number of ciphers in decimals; thus, $(514.0)^2=+6$, $(51.4)^2=+4$, $(5.14)^2=+2$, $(.514)^2=0$, $(.0514)^2=-2$, $(.00514)^2=-4$, etc. The following is a general rule for finding the position of the decimal point in all expressions of the first or second degree :

Rule III.—First. When the slide is direct. Figures on line A reading in the same direction as those on lines B and C.

If the number on line A, both in setting and reading, is either greater or less than the number opposite on line B, the number of places in the result is the algebraic difference between the sum of the number of places in the numerator and in the denominator.

If the number on line A is greater in setting and less in reading than the number opposite on line B, the number of places in the result is the algebraic difference as above, plus one.

If the number on line A is less in setting and greater in reading than the number opposite on line B, the number of places in the result is the algebraic difference as above, minus one.

Second. When the slide is reversed. Figures on line A reading in an opposite direction to those on lines B and C.

The number on line A in setting is to be compared with the number on line B in reading, and the number on line A in reading with the number on line B in setting. Otherwise the rule remains unchanged.

The above rule may be expressed as follows :

Slide Direct.

Setting.	Reading.	Result.
$A > B$	and $A > B$	Algebraic difference.
$A < B$	" $A < B$	" "
$A > B$	" $A < B$	" " $+1$
$A < B$	" $A > B$	" " -1

Slide Reversed.

S. R.	R. S.	Result.
$A > B$	and $A > B$	Algebraic difference.
$A < B$	" $A < B$	" "
$A > B$	" $A < B$	" " $+1$
$A < B$	" $A > B$	" " -1

It will be found that the foregoing rule has certain characteristics by which it can be easily remembered and applied.

A variety of examples illustrating the application of the preceding rules and directions will be given after some other varieties of the instrument have been considered.

If, instead of the line of roots C, a line similar to A or B is laid down in an inverted position, all numbers on this line are the reciprocals of those opposite on line B, and as multiplying by a number is the same as dividing by its reciprocal, we are enabled to multiply three numbers together by a single operation, as follows :

Set the first number on the slide to the second number on the lower fixed line, then opposite the third number on the upper fixed line will be found the answer on the slide.

I have here, for your inspection, an instrument of this description. I use it to some extent and find it very convenient.

A rule for first power computations having a length of scale equal to the length of rule, or double the ordinary length, may be

obtained by commencing the scales on the upper line of slide and upper fixed line at the left and on the lower line of slide and lower fixed line at the centre of the rule. This is superior to the ordinary rule in accuracy of reading, but requires a sacrifice of roots and powers. I have here, and will pass around, an instrument of this description.

Instruments for first power computations are sometimes made in the form of a circle. The logarithmic scale is marked on the circumference of a circular plate, also on the inner edge of a ring to which it is fitted. By revolving the plate, any part of one scale is brought opposite any required part of the other.

Many varieties, both decimal and duodecimal, have been designed for special purposes. One, having a line of logarithmic sines on one edge of the slide and a line of logarithmic tangents on the other, has been used for the solution of trigonometrical formulæ, but the ordinary rule, aided by a table of natural sines and tangents, will be found to answer every purpose. Some rules have single and triple lines working together, and are useful in finding cubes and cube roots.

Many other varieties, specially adapted to some particular class of work, such as gauging casks, measuring timber, computing horse power, estimating compound interest, etc., have been used, some of them to a considerable extent, but I will not enter into a description of them here.

Instruments in which double lines on the slide work between single and double fixed lines are, of all varieties, applicable to the greatest number of useful problems.

The value of the slide rule as a calculator depends upon the accuracy of its results, upon the rapidity with which these results can be found, and upon the mental and mechanical effort required in the solution.

Results by the slide rule are necessarily approximate, the degree of approximation depending upon the length of scales and the care observed in the manufacture. On the ordinary 12 inch rule of single and double lines, the lengths of scales are 5½ inches and 11 inches respectively. These have been manufactured to some extent in this country. Many carpenters carry them in their pockets who have not the most remote idea of the use for which they are intended. I have present, for your inspection, a rule of this description.

The 24 inch rule having a length of scale of 11 inches for first power computations and 22 inches for roots, gives a degree of approximation sufficient for many purposes of the engineer and architect. It can be used with great advantage when results beyond the third place are not essential. Rules of this description, so far as I am aware, cannot be obtained in this country. I have present, for your inspection, a fine imported instrument of this length, manufactured by W. F. Stanley, of London.

On the back of the rule may be found a variety of gauge points, to the use of which I will hereafter call your attention.

The instruments heretofore noticed are well fitted for rough calculations and as a check on ordinary methods, but do not give results with sufficient accuracy to satisfy the requirements of ordinary business.

I will next call your attention to some varieties of the instrument that are not confined to rough approximations, but can be used for any except the most refined calculations of the engineer and actuary, as well as for the great majority of money transactions. I have present, for your inspection, a spiral slide rule designed and patented by George Fuller, professor of engineering in the Queen's College, Belfast, and manufactured by W. F. Stanley. It consists of a cylinder that can be moved up and down and revolved about a second fixed cylinder to which a handle is attached. Upon the outer cylinder is wound in a spiral a single logarithmic scale; fixed to the handle is an index. A third cylinder slides and revolves within the second, to which is attached two other indices whose distance apart is the axial length of the complete spiral. These movements allow the fixed or moving indices to be brought to any part of the scale. This instrument is practically confined to first power computations. The inventor gives a method for higher powers, but remarks that "for any power not higher than the seventh, the quickest way is by direct multiplication." I do not discover that the instrument for examples involving roots and powers possesses much if any advantage over a table of logarithms. We have seen that on the ordinary 12 inch rule the length of scale for first power computations is $5\frac{1}{2}$; on the spiral rule it is 41 feet 8 inches. On the ordinary rule the first figure is printed on the rule; on the spiral the first three figures are printed throughout its length. The fourth figure is represented by a mark, or is midway between two marks, and the fifth figure is estimated by the eye. Results can generally

be found correct to five places, and for almost every class of work it would be a waste of time to carry them beyond this limit. This instrument will solve examples of the form of $\frac{a \times b \times c}{m \times n}$ by the following rule: Bring a to the fixed index. Set one of the movable indices to m. Bring b to one of the movable indices. Set one of the movable indices to n. Bring c to one of the movable indices; and so on until the last factor of the numerator is reached. The result will then be read at the fixed index.

I will next call your attention to a cylindrical slide rule of my own design. I have here a model for your inspection. The rule consists of a cylindrical slide, provided with a knob at each end, which admits of both lateral and longitudinal motion with respect to a circumscribing envelope of triangular parallel bars. Rings at each end rigidly connect the bars, and are provided with journals fitting supports attached to the base.

The slide may be held and the envelope be revolved, or the envelope may be held and the slide be revolved, or both may be revolved simultaneously.

Upon the slide are wound two logarithmic scales, one on each side of an imaginary centre line.

Each scale is divided into any desired even number of parts of equal length. The number of parts is double the number of bars, and the length of each one-half the graduated length of the rule. These parts are laid off lengthwise upon and at regular intervals around the cylinder. They follow each other in regular order both on the right and left, and those on the right follow those on the left in regular order. The figures and divisions on the scales are made to face both ways, that they may be read from either edge of the bars. Upon the lower line of the bars, and in contact with the slide, are two additional logarithmic scales, of the same length and laid off in the same order as those on the slide, there being a complete scale both on the left and right of the centre. When the commencement of the scales on the slide and envelope are in contact, all divisions on the one are opposite corresponding divisions on the other. Upon the upper lines of the bars, and not in contact with the slide, is one additional logarithmic scale, or line of roots.

This scale is divided into double the number of parts as the others, the length of each being one-half the graduated length of the

rule, and occupies the entire upper part of the bars both on the left and right of the dividing centre line. The parts composing the first half of the complete scale extending from 1 to the $\sqrt{10}$ are laid off on the left, commencing on the same bar and immediately above the first part of the scale, on its lower line, and extend around the envelope in regular order until that scale is covered.

The parts composing the last half extending from the $\sqrt{10}$ to the end of scale, commence on the right, on the same bar and immediately above the first part of the scale on its lower line, and extend around the envelope in regular order until that scale is covered.

The result of this arrangement is, that any number represented on the lower line of bar is the square of the number opposite to it on the upper line, and any number represented on the upper line of bar is the square root of the number opposite to it on the lower line. Roots of numbers having 1, 3, 5, 7, etc., or an odd number of places, being found on the left, and those having 2, 4, 6, 8, etc., or an even number of places, being found on the right.

When the slide is set in position for use, the divisions on the slide appear of about equal length on either edge of the bars, and two lines of figures marking their value appear in each opening between the bars, two similar lines also being covered by each bar. The divisions on the upper line of the bars are transferred to the slide by means of a pointer fitting over the bars. This pointer is also convenient for retaining the position of any division on either line while the slide is being revolved into the required position. The slide will be known as A, the lower line on the bars as B, and the upper line on the bars as C. This instrument will solve any problem previously mentioned as within the capacity of the ordinary slide rule, and the same general rules I, II and III apply; but as the manipulations are very different, I will repeat Rule I in terms better suited to this particular instrument, after which no difficulty will be found in applying the remaining ones.

In the solution of problems of the form

$$\frac{ax}{b} \quad \frac{ax^2}{b} \quad \frac{ax}{b^2} \quad \frac{ax^2}{b^2} \quad \frac{ab}{x} \quad \frac{ab^2}{x} \quad \frac{ab}{x^2} \quad \frac{ab^2}{x^2}$$

proceed as follows:

Turn the instrument in the standards until b appears in convenient position on the envelope on line $\left\{\begin{matrix}\text{B if 1st power}\\ \text{C if 2d }\ \text{“}\end{matrix}\right\}$. Hold the

envelope in about this position, and turn the slide until *a* is seen facing the line of bar on which *b* was found. Then move the slide backward or forward until *a* is brought opposite to or in contact with *b*. (Use the pointer if necessary). The instrument is now set, and need not be changed so long as *a* and *b* remain the same. Leave the slide in this position and turn the envelope in the standards until *x* is seen on the line $\left\{\begin{matrix}\text{B if 1st power}\\ \text{C if 2d ``}\end{matrix}\right\}$ opposite to which, on A, the answer will be found.

It will be observed that by rotating either the slide or envelope, or both, any half line on the slide may be brought in contact with any desired half line on the bars, and that by the longitudinal motion of the slide any two graduations or sub-divisions in those half lines may be brought in contact, or made to register, without moving the end of the slide beyond the centre line of the envelope; and, further, that when so set, complete logarithmic scales will be found in contact for direct comparison—one on the lines of the slide, and one on the lower lines of the bars. This is true for every required setting of the rule. Consequently the scales on slide and envelope being set for any given ratio, such ratio may be multiplied by every possible number within the reading limits of such scales, and the results be read without a resetting of the rule.

The setting and reading can be accomplished with great rapidity after once becoming familiar with the movements. The lateral movement need never exceed half of a revolution, nor the longitudinal movement more than one-quarter the length of the slide.

W. F. Stanley is now engaged in engraving the scales for an instrument of this description. I fixed upon a length of scale of thirty feet for first powers, and sixty feet for roots. This will produce results with sufficient accuracy to satisfy almost any requirement, and will give a convenient size for use. The first three figures will be printed upon each scale throughout. The fourth figure, between 1000 and 6500, will be represented by a mark; and from 6500 to 10,000 will be represented by a mark, or be midway between two marks. The fifth figure can usually be determined by the eye. The slide will be four inches in diameter, and have a divided length of eighteen inches, and the envelope will contain twenty bars. It will be equal to an ordinary slide rule of forty times its length, or sixty feet. As compared with the spiral rule, I do not claim for it any greater accuracy, but that it has a much wider range, and that results are determined with incomparably greater rapidity.

It has been seen that in solving the form $\frac{ax}{b}$, the spiral requires three settings for the first result, and an additional setting for every additional value of x, while the cylinder requires but one setting for the first result, and no additional settings for every possible value of x.

It is believed that in this instrument will be combined all of the most desirable features of a calculating rule, viz., reliability, rapidity of manipulation, wide range of application, and a minimum of mental or physical effort. It is not to be supposed that any instrument will do away with brain work; only with the drudgery of it. It is necessary to have a clear idea of the operations to be performed and state them accordingly, but most of the time spent in mere arithmetical workings is a waste of effort.

It may be asked by some, If the slide rule is an instrument of such vast utility, why, after the lapse of two hundred years, has it not attained a more general use? I cannot answer this question in a manner fully satisfactory to myself, but can give some reasons which, undoubtedly, have been largely instrumental in producing this result.

First. No effort has been made to bring it properly before the public, and think I am correct in stating that there are many, even among engineers, who have never heard of the instrument.

Second. Many suppose that it is very difficult, or next to impossible to understand or use, and feel a disinclination to subject themselves to such laborious and long-continued effort. A more erroneous conception could not be formed. Thirty minutes of well directed instruction would generally be sufficient to impress upon a learner every necessary movement.

Third. The instruments found in the market have no instructions with them, and the gauge points marked on the back would be about as intelligible if written in Choctaw.

Most persons who use them have acquired the knowledge unaided.

Fourth. Many books written on the subject are worse than useless; while professing to give simple directions, they give a separate rule for each operation. None of them can be associated in such a way as to be easily retained, and the memory is burdened with more than it can carry.

I have examined some of these books, though happily not until after I had become perfectly familiar with every movement. By following their directions I should have despaired of ever being able to master it.

Fifth. The impression prevails that the instrument is of advantage only to those having constant use for it, and not suited to such as have only a little figuring to do now and then. This is a great mistake. If learned in the right way, a knowledge of its use will never be forgotten, and will always be available for instant application. If one has not work that will occupy him for more than twenty minutes in a day, it is better to do it in five minutes, and pass the other fifteen in rest or some other more congenial or profitable employment.

It is the most valuable aid to mathematical science that could possibly be devised. It should be taught in all our schools, as I understand it is in many schools abroad. Young America will have to take hold of this matter.

Sixth. No good instruments, so far as I am aware, can be obtained in this country, and few are inclined to go to the trouble and expense of importing them.

Seventh. Many suppose that the instrument cannot be relied upon, and that it is much safer to figure in the old way. This is the most serious objection of all, and when applied to the ordinary slide rule often holds good, for results cannot be found beyond the third place, while many engineering and most business problems require more than this; but, so far as it goes, it is more reliable than the ordinary method; mistakes are less liable to occur, and if they should occur, the whole work is almost instantly checked. Advocates of the instrument often claim for it more than it will justly bear. They will tell you to work problems in interest, discount, etc., with an ordinary six inch slide. Problems of this kind require the cents as well as the dollars, and are beyond the capacity of the ordinary rule. By making use of the spiral or cylindrical rule, however, this objection is overcome.

Slide rule problems may be divided into three general classes:

First. Those which require but one setting and one reading.

Second. Those which require but one setting, but two or more readings.

Third. Those which require two or more settings and readings.

The first class embraces all formulæ heretofore given except the one used in describing the applications of the spiral rule.

In the second class the second factor of the numerator is composed of two or more quantities of the first or second degree connected by the signs + or —, as $\frac{a(x+y+z^2+u^2)}{b}$, or $\frac{a(x+y+z2).}{b^2}$.

Rule I applies. It is only necessary to take a reading opposite each part of the second factor and add the results.

The third class embraces all formulæ which may be brought to the first or second class by factoring, as

$$\frac{a^2x^3}{b^2c} = \frac{ax^2}{b^2} \times \frac{ax}{c} \text{ or } \frac{a \times b \times c \times d}{m \times n} = \frac{a \times b}{m} \times \frac{c \times d}{n}$$

The first class is much the largest and most important, and the only one that need be further considered, for if this is well understood, no difficulty will be found with the others.

The examples on the next page will fully illustrate the application of the rule.

Reciprocals.—Reverse the slide. Set 1 on A to 1 on B, then any number on A is the reciprocal of the number opposite on B, and *vice versa*. Also, any number on A is the reciprocal of the square of the number opposite on C.

MISCELLANEOUS APPLICATIONS.

—Pay Rolls—

$$\frac{(\text{Rate per day}) \times (\text{Number of days})}{1} = \text{Amount.}$$

Example.—17 days and 5 hrs. at $1.60 per day $= \frac{1.60 \times 17.5}{1} = \$28.00$

$$\frac{(\text{Rate per week}) \times (\text{Number of days})}{6} = \text{Amount.}$$

Example.—9 days and 7 hrs. at $8.00 per week $= \frac{8.0 \times 9.7}{6} = \$12.93$

$$\frac{(\text{Rate per month})\times(\text{Number of days})}{(\text{No. of working days in the month})} = \text{Amount.}$$

Example.—16 days & 9 hrs. at $45 per month $= \frac{45.0\times 16.9}{26} = \$29.23$

—Pro Rata—

$$\frac{(\text{Gen. Ex. Acc.})\times(\text{Acc. A})}{(\text{Total of Accts.})} = \text{Amount going to A.}$$

Example.—$540.00 are to be divided pro rata among various accounts, amounting in the aggregate to $7500. Required the amount going to an account of $347.00 $\frac{540\times 347}{7500} = \$24.98$

The amount going to all other accounts can be read off without additional setting.

The value of the slide rule in questions of this nature, which are of constant occurrence in business, is beyond estimate. It applies to Taxes, Fellowship, Exchange, Conversion of Foreign and Domestic Weights and Measures, the majority of Estimates of Strains Sections, Quantities and Cost, in fact a very large percentage of all calculations.

—Cask Gauging—

Rule by Thomas Kentish.

If l = length, "H = Head Diam., "B = Bung Diam.

$$\frac{1\times(H^2\times 2\,B^2)}{(33)^2} = \text{Gallons.}$$

Example:

$l = 28''$, $H = 23''$, $B = 28''$

$$\frac{28\times[(23)^2+2\times(28)^2]}{(33)^2} = 13.6+40.3 = 53.9 \text{ Gallons.}$$

—Mensuration—

$$\text{Circum. of Circle} = \frac{3.1416\times\text{Diam.}}{1}$$

$$\text{Area of Circle} = \frac{.7854\times(\text{Diam.})^2}{1}$$

$$\text{Area of Ellipse} = \frac{(\text{Major axis})\times(\text{Minor axis})}{1.273}$$

No.	Formula	Statement.	Example.	SOLUTION.
1	ax	$\frac{ax}{1}$	$\frac{4.3\times 9.65}{1}=41.5$	Set 43 on A to 1 on B. Op. 965 on B read 415 on A.
			D.P.$(1+1)-1+1=+2$	$43>1$ and $415<965$ = Alg. Diff.+1
2	$\frac{x}{b}$	$\frac{1\times x}{b}$	$\frac{1\times 467}{29}=16.1$	Set 1 on A to 29 on B. Op. 467 on B read 161 on A.
			D.P.$(1+3)-2=+2$	$1<29$ and $161<467$ = Alg. Diff.
3	$\frac{ax}{b}$	$\frac{ax}{b}$	$\frac{16.0\times .013}{41.0}=.00507$	Set 16 on A to 41 on B. Op. 13 on B read 507 on A.
			D.P.$(2-1)-2-1=-2$	$16<41$ and $507>13$ = Alg. Diff.—1
4	ax^2	$\frac{ax^2}{1}$	$\frac{3.5\times(37.0)^2}{1}=4790$	Set 35 on A to 1 on B. Op. 37 on C read 479 on A.
			D.P.$(1+4)-1=+4$	$35>1$ and $479>137$ = Alg. Diff.
5	$\frac{x^2}{b}$	$\frac{1\times x^2}{b}$	$\frac{1\times(0.73)^2}{.037}=14.4$	Set 1 on A to 37 on B. Op. 73 on C read 144 on A.
			D.P.$(1+0)+1=+2$	$1<37$ and $144<53$ = Alg. Diff.
6	$\frac{ax^2}{b}$	$\frac{ax^2}{b}$	$\frac{4.0\times(7.5)^2}{5.0}=45.0$	Set 4 on A to 5 on B. Op. 75 on C read 45 on A.
			D.P.$(1+2)-1=+2$	$4<5$ and $45<56$=Alg. Diff.
7	x^2	$\frac{1x^2}{1}$	$\frac{1\times(6.1)^2}{1}=37.2$	Set 1 on A to 1 on B. Op. 61 on C read 372 on A.
			D.P.$(1+2)-1=+2$	$1=1$ and $372=372$ = Alg. Diff.
8	a^3	$\frac{a\times a^2}{1}$	$\frac{3.4(\times 3.4)^2}{1}=39.3$	See No. 4.
9	$\frac{ax}{b^2}$	$\frac{ax}{b^2}$	$\frac{16.3\times 18.1}{(8.7)^2}=3.90$	Set 163 on A to 87 on C. Op. 181 on B r'd 390 on A.
			D.P.$(2+2)-2-1=+1$	$163<76$ and $39>18$ = Alg. Diff.—1
10	$\frac{ax^2}{b^2}$	$\frac{ax^2}{b^2}$	$\frac{2.5\times(0.73)^2}{(.037)^2}=973$	Set 25 on A to 37 on C. Op. 73 on C read 973 on A.
			D.P.$(1+0)+2=+3$	$25>137$ and $973>535$ =Alg. Diff.
11	$\sqrt{\frac{bx}{a}}$	$\sqrt{\frac{bx}{a}}$	$\sqrt{\frac{7.5\times 19.4}{6.75}}=4.64$	Set 675 on A to 75 on B. Op. 194 on A read 464 on C.
12	$\sqrt{\frac{b^2x}{a}}$	$\sqrt{\frac{b^2x}{a}}$	$\sqrt{\frac{(2.8)^2\times 13.2}{46.0}}=15.0$	Set 46 on A to 28 on C. Op. 132 on A read 15 on C.
13	$\sqrt[3]{a}$	$\sqrt[3]{a}$	$\sqrt[3]{216.0}=6$	Reverse Slide. Set 216 on A to 1 on C. Op. 6 on A read 6 on C.

D. P.—Decimal Point, See Rule III.

$$\text{Area Parabola} = \frac{(\text{Chord}) \times (\text{Height})}{1.5}$$

$$\text{Surface of Sphere} = \frac{3.1416 \times (\text{Diameter})^2}{1}$$

$$\text{Convex Surface of Cylinder} = \frac{(\text{Diam.}) \times (\text{Height})}{.3183}$$

$$\text{Convex Surface of Cone} = \frac{(\text{Diam.}) \times (\text{Slant Height})}{.6366}$$

$$\text{Solidity of Sphere} = \frac{(\text{Diam.}) \times (\text{Diam.})^2}{1.91}$$

$$\text{Square Yards} = \frac{(\text{Length in feet}) \times (\text{Width in feet})}{9}$$

$$\text{Lineal yards 27}'' \text{ wide} = \frac{(\text{Length in feet}) \times (\text{Width in feet})}{6.75}$$

Examples of class might be continued indefinitely, but I will pass on to the consideration of another large and important class for which the slide rule possesses great advantages over any other means of calculation.

GAUGE POINTS.

Various questions of a complex nature are worked with great facility by the use of previously calculated and tabulated constants called gauge points, which are used for all similar questions.

These are found by combining the constants of any general formula, shifting them from the numerator to the denominator, or the reverse if necessary, by reciprocals, and thus reducing to one of the general forms applicable to the slide rule.

As no careful man would care to make use of gauge points unless he can prove them correct, the derivation of those employed will be given.

The following applications will be sufficient to illustrate their time saving properties :

SIMPLE INTEREST.

$$\text{Int.} = \frac{(\text{Principal}) \times (\text{Rate}) \times (\text{Time in days})}{100 \times 360} = \frac{(\text{Principal}) \times (\text{Time in days})}{g}$$

in which $g = \frac{36000}{\text{Rate per ct.}}$ { Rate $4\frac{1}{2}$ per cent. $g = 8000$; " 6 " $g = 6000$; &c. &c.

Example.—\$478.50 for one year 2 months and 14 days @ $4\frac{1}{2}$ per cent. $= \frac{478.50 \times 434}{8000} = \$25.96.$

Example.—\$743.80 for 5 months and 16 days @ 6 per cent. $= \frac{743.80 \times 166}{6000} = \$20.58.$

COMPOUND INTEREST.

$$\text{Amount} = \frac{(\text{Principal}) \times \left(1.00 + \frac{Rate}{100}\right)^n}{1} = \frac{(\text{Principal}) \times (g),}{1}$$

in which g = principal and interest of \$1.00 for the given rate and time.

Example.—What will \$250.00 amount to at compound interest in 10 years at 6 per cent.?

We find, from a table previously calculated, g=1.791. Amount $= \frac{250.00 \times 1.791}{1} = \$447.75.$

7 years at 4 per cent. g=1.3159
9 " " $5\frac{1}{2}$ " " g=1.6191 } &c.

WEIGHTS OF MATERIALS.

$$\text{Weight} = \frac{(\text{Length}) \times (\text{area})}{g}$$

in which g is the reciprocal of the weight of a unit of volume.

Length in feet. Area in feet, g=Reciprocal of weight of 1 cubic foot.

Length in feet. Area in inches, g=Reciprocal of weight of 12 cubic inches.

Length in inches. Area in inches, g=Reciprocal of weight of 1 cubic inch.

DIMENSIONS.

MATERIAL.	F. F.	F. I.	I. I.
Wrought iron	.00208	.300	3.6
Granite	.00588	.847	10.16
White pine	.0333	4.8	57.6

Examples.—The weight of a bar of wrought iron 17.3 feet long and 4.75 square inches area $= \frac{17.3 \times 4.75}{.300} = 274$ lbs.

The weight of a block of granite $8'' \times 12'' \times 24'' = \frac{96 \times 24}{10.16} = 226.8$ lbs.

The weight of a stick of white pine $1' \times 2' \times 18' = \frac{2 \times 18}{.0333} = 1081$ lbs.

Gauge points for cylinders and spheres are made with equal facility and will be found on most rules, though so far as I have observed, without any means of determining the true value of the result.

The weight of one piece of any material of any required section may be readily found by the use of gauge points of the above description, but for some materials like wrought iron or steel, which are used to a large extent, it will be found of great advantage to make a table giving the gauge point for each number of pieces from 1 to 100. They may be made with reference either to a given area or a given weight per lineal foot.

By this means the weight of any number of pieces of any length and of any area or weight per foot may be found by one operation. For wrought iron if only one table is made, one having reference to a given weight per foot will be found the most useful, for shape iron is usually ordered in this way, and the weight per foot of any area of bar iron can be found mentally.

The following will show the way in which such tables are made

(1.) Total wt. $= \frac{(\text{Length in ft.}) \times (\text{wt. per ft.})}{g}$ in which $g = \frac{1}{\text{No. pieces}}$

(2.) Total weight $= \frac{(\text{Length in ft.}) \times (\text{Area in sq. in.})}{g}$ in which

Rec. of wt. of bar 1′ long 1″ square.

$$\text{For steel } g=\frac{\text{No. pieces.}}{\text{No. pcs.}}=\frac{.2941176}{\text{No. pcs.}}$$

From tables of gauge points for wrought iron and steel we will find :

For 16 pieces wrought iron, g=.0625 From (1)
" 28 " steel, g=.0105 " (2)

Example.—The weight of 16 pieces of wrought iron 17.4 ft. long and 19.7 lbs. per ft.$=\frac{17.4\times19.7}{.0625}=5484$ lbs.

Example.—The weight of 28 pieces of steel 24.5 ft. long and 8.4 sq. in. area$=\frac{28\times8.4}{.0105}=22400$ lbs.

The weight of sheet metals may be found with equal facility :

$$\text{Weight}=\frac{(\text{Length in inches})\times(\text{width in inches})}{g}$$

$$\text{For one piece } g=\frac{144}{\text{Weight per square foot.}}$$

$$\text{For any number of pieces } g=\frac{144}{(\text{No. pcs.})\times(\text{Weight per sq. ft.})}$$

Example.—The weight of 20 sheets of wrought iron 31″×66″ No. 20 B. G.$=\frac{31\times66}{5.143}=397.8$ lbs.

MEASURES OF CAPACITY.

Dimensions are given in feet, inches, or both, and the cubic contents are required in inches, feet, yards, perches, gallons, bushels, etc.

The gauge point of any unit of measure is the value of that unit expressed in terms of the unit of the given dimensions.

Examples.—U. S. Bushel (3 dimensions in ft.) g=1.244.

U. S. Gallon (3 dimensions in inches) g=231.0.

The No. of U. S. bushels in a bin 3′×4′×7′$=\frac{12\times7}{1.244}=67.52$ bush.

The number of U. S. gallons in a box $16''\times12''\times8''=\frac{16\times96}{231}$ $=6.65$ gallons.

Gauge points adapted to cylinders and spheres are readily made and will be found in most rules. They are used as follows :

For Cylinders. $\frac{(\text{Height})\times(\text{Diam.})^2}{g}=\text{Result.}$

For Spheres. $\frac{(\text{Diam.})\times(\text{Diam.})^2}{g}=\text{Result.}$

FEET BOARD MEASURE.

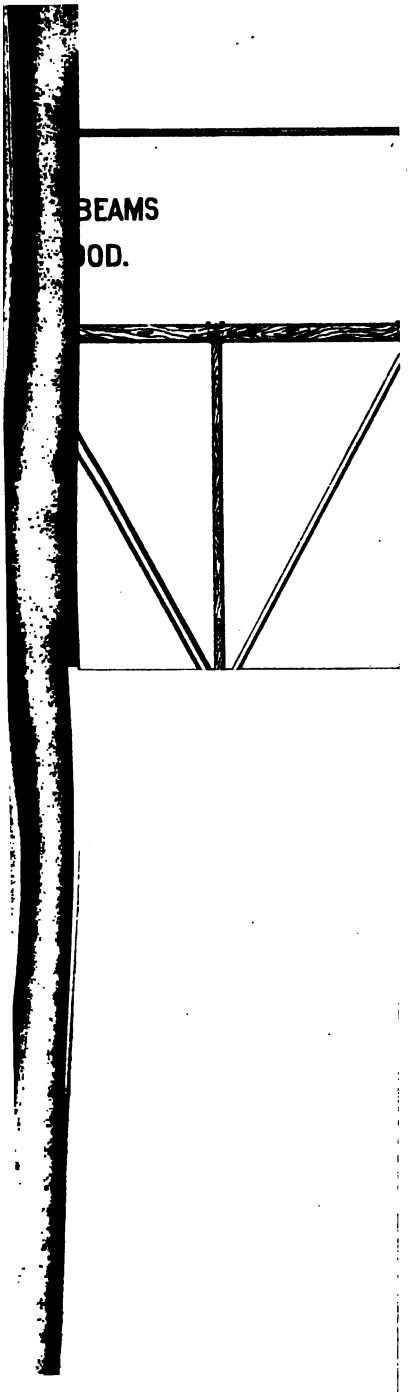
B. M. $=\frac{(\text{No. pcs.})\times(\text{Length})\times(\text{Section})}{12}=\frac{(\text{Length})\times(\text{Section})}{g}$ in which $g=\frac{12}{\text{No. pcs.}}$ tabulate the values of g up to say 100 pieces.

Example.—24 pcs. 7″×14″—26′.0″ long $=\frac{98\times26}{.5}=5096$ B. M.

I will not continue the subject further. Useful applications might be given to an extent sufficient to fill a good sized volume, but enough has been said and a sufficient number of examples have been given to call your attention to the great advantage which the slide rule possesses as a means of rapid calculation.

It is hoped that each of you who are not familiar with the instrument will investigate it for yourself. The time thus spent will never be regretted, and you will soon be able to profitably employ it in the solution of a great variety of useful problems; but whether the object in view be information, recreation, or business application, it will be found well worthy of your attention.

Ordinary 12 inch slide rules can be obtained at most hardware stores at a cost of about $1.25, which will answer every purpose for becoming familiar with the rules and their application to the various classes of examples. They will also be found useful as a check and for approximate calculations. Rules on which the lower line commences at 1 on the left and ends at 10 on the right should be selected.



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COMBINATION BRIDGES—THEIR MERITS AND THEIR COST.

A COMPARISON WITH HOWE TRUSS BRIDGES.

By C. L. Strobel, C. E.

[Read April 18, 1882.]

It is my purpose to describe the essential and distinctive features of the combination bridge, and in connection therewith to treat of those properties of timber which have an important bearing upon its use for constructive purposes; to discuss certain truss forms commonly used; and to compare the merits and cost of the combination and the Howe truss bridge.

The immediate occasion for these remarks is the conviction that the combination bridge is not as generally known and appreciated as it deserves to be, and that very erroneous opinions prevail as to its cost. While the subject is not a new one, I may claim for it, that it has not, so far, received more than passing notice in any published work; and I think the comparative table of cost, which I shall present, will be found to contain results very unexpected to many engineers.

The combination or composite bridge owes its name to the use of two materials, wood and iron, conjointly in its construction. The term is, however, applied to such truss bridges only, the tension members of which are of iron and the compression members of wood. It does not include the Howe truss bridge; for, although

those of its web members which are strained in tension—viz., the vertical rods—are of iron, the bottom chord, also a tension member, is of wood. And as the older forms of all wood bridges, the "Long" and the "Town," have gone out of use altogether, and the Howe truss, of the bridges now built, is more nearly a wooden bridge than any other, it is usually classed as such.

The Howe truss bridge is of American origin, and no doubt more bridges of this kind have been built in the United States to the present day than of any other. It is also well known in Europe, and frequent examples of it are to be met with there. It owes its superiority over the older forms of wooden bridges, which it supplanted, to the use of iron for a portion of its tension members, and I shall show that, similarly, the combination bridge is a better bridge than the Howe truss, chiefly for the reason that all of its tension members are of iron.

The combination bridge is not only also of American origin, but it is a bridge which is impossible with European methods of joining the members by means of rivets, and the type is therefore especially peculiar to this country. It furnishes a striking illustration of the capabilities of pin connections as used in American iron truss bridges, and further attests the superiority of these over riveted joints, a superiority which is admitted both constructively and economically by unprejudiced European engineers.

The obstacles in the way of the successful employment of wood as a material in bridge construction may be classed under two principal heads: Its quality of shrinking in seasoning, and its small shearing strength along the grain. Of minor constructive, though not of less economic consequence, is its perishable nature and the uncertainty, within wide limits, of its strength.

SHRINKAGE OF TIMBER.

The percentage of shrinkage is much larger across than with the grain. It varies very much for different timbers, nor is there much uniformity for even the same kind of timber or for pieces cut from different parts of the same tree. The following are some of the average values given for European timbers:

	Along the grain. Per cent.	Across the grain. Per cent.
Black Ebony	.010	3.1
Oak	.2 to .3	3.6
Ash	.187 " .821	5.7
Pine, Norway Spruce	.076	3.3
Cherry (Prunus avium)	.112	7.3
Mahogany	.110	1.4
Poplar, silver	.086 " .629	4.5
" black	.125	4.3

In the Howe truss bridge the braces, through the interposition of cast angle blocks, abut against the under and top sides of the wooden chords, but the rods being adjustable, the shrinkage of the timber is provided for by screwing them up from time to time, and the members are thereby prevented from working loose. No such adjustment was possible in the Long and Town trusses. These invariably became loose and shaky in a short time after they were put up, and this contributed in a great measure to their want of success.

Shrinkage along the grain being generally very small, the opinion is quite prevalent that there is none at all in this direction, but the above table shows that it may be as much as 1″ in 30′ for oak, and 2″ in 30′ for poplar. The fact that shrinkage does take place along the grain should never be lost sight of, though it is so small that, ordinarily, it need not be considered.

In the combination truss the timbers abut on end and shrinkage simply reduces the camber. By calculating the lengths of the wooden members with an allowance for shrinkage, or, as is more generally done, by providing originally a slightly larger camber than is customary in an iron bridge, no inconvenience will be experienced. But in combination as well as wooden bridges, the bolts which pass sidewise through the timber and are used to hold the sticks in position or to pack them together, including the track bolts through cross-ties in iron bridges, require screwing up after a time, and where the bolts are in a vertical position, the nuts should be locked in some manner so they will not work off and either the bolt or the nut drop to the ground and be lost.

TENSILE CONNECTIONS.

The second great obstacle in the way of the employment of wood in bridge construction, its low shearing strength along the grain,

makes it extremely difficult, if not impossible, to devise satisfactory tensile connections. A few simple considerations will at once make this apparent.

Fig. 1.

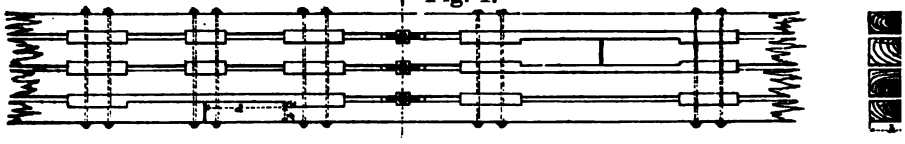


Figure 1 represents the usual method of splicing the lower chord sticks in a Howe truss if wooden clamps are used. The outer stick is generally made of smaller thickness than the middle stick, and only one clamp is used for it, while two are used for the middle stick.

The depth of the notching t reduces the strength of the stick and represents so much waste. If the clamp is to transfer the full strain in the chord stick, the resistance to shear along d and the resistance to crushing at t must equal the tensile strength of the stick across b. The resistance to shear along the grain for white pine is about 600 lbs. per square inch, while its tensile strength = 10,000 lbs. per square inch. In order, therefore, that the shearing strength along d be equal to the tensile strength across b, 600 dh must equal 10,000 bh, h representing the depth of the stick, or $d=17b$.

Let $b=4''$, then $d=5'-8''$, and $2d=11'-4''$. But the panel length in Howe truss bridges is restricted to about 10′, and it would therefore be necessary to make the clamps longer than the panel length, which is inadmissible, since it is necessary to splice another stick in the next panel.

In the web members of the Long and Town trusses, the tension members were notched over the chords or held by tree nails, but even if the sticks were allowed to project beyond the chords considerably, it is evident that no satisfactory connection was possible. In the lower chords of the Howe truss the difficulty is met by providing an excess of timber in the chord sticks; by making them very long; and by keying them together, so that one stick can transfer a portion of its strain to the adjoining stick, through the keys and the tubes of the angle blocks. The clamps are then proportioned as only a partial splice for the chord stick, and the stick spliced is not counted in as part of the effective section of the chord. All this entails extra expense, and at best there is so large

an element of uncertainty in the effectiveness of the splicing—the intricate course of the stress from one stick to another through the keys, tubes, clamps, and bolts, is past computation—that the Howe truss is far from satisfying modern demands on a first-class bridge, one of which requires the employment of such forms of construction only which admit of the determination of the strain in all parts with precision and certainty.

THE COMBINATION BRIDGE.

In the combination truss all the timber is used to its best advantage. It is in simple compression, abutting squarely on end against cast iron shoes. The several sticks forming one member are keyed and bolted together so as to act in unison. The framing is very simple, more so than in the Howe truss, and long sticks of timber are avoided.

Timber exposed to the weather, as is well known, begins to rot first where it is in contact with other timber, because the moisture is retained longest at such points of contact. Hence cast iron keys are preferable to wooden ones, and hard wood keys to soft wood keys. By using cast iron keys in combination bridges, wood in contact with wood very seldom occurs and can be avoided altogether, and it is a matter of comparatively small expense to provide the compression members with sheet iron or tin roofing and thereby increase the durability of the timber greatly.

The centre lines of stress intersect at joints in the centres of the pins, avoiding the cross strains from eccentricity which occur in the Howe truss, and all strains are clearly defined and can be calculated with precision. The castings are simple joint boxes, very similar to those used in iron bridges with closed compression members.

BEST KIND OF TRUSS.

The two plates accompanying this paper represent the well known Warren or single triangular form of truss.

In iron, the Pratt or single quadrangular for short spans, and the Whipple or double quadrangular for long spans, are more commonly used; and as these forms of trusses have also been frequently applied to combination bridges and are somewhat cheaper in first cost than the Warren, it becomes necessary to call attention to the objections attaching to their use.

The Pratt and Whipple trusses, like the Warren, consist of a series of triangles between parallel top and bottom chords, but these

triangles have one right angle each—one of their sides being vertical—while in the Warren truss they are equilateral.

In the Warren truss the middle braces are proportioned to resist both tension and compression as the position of the load on the bridge may require, but the diagonal members or ties of the Pratt and Whipple trusses are designed to take tension only, and counter diagonals are provided, which take the stress, when the main ties, without their use, would be compressed. It is these counter ties which make the Pratt and Whipple form of truss objectionable for the combination bridge, because they are necessarily subject to excessive strains from temperature, as the following consideration will show:

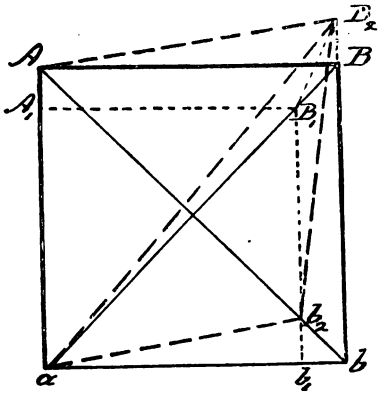


Diagram represents a panel of a Pratt truss; *AB* and *ab* are the chords, *Aa* and *Bb* posts, *Ab* a main tie, and *aB* the counter tie. *aA*, *AB* and *Bb* in the combination truss are of wood, *ab* and the diagonals, *Ab* and *Ba*, of iron. The full lines are high temperature lines, and it is proposed to show the deformations of the figure and the strains produced in the members by a change to low temperature.

If the modulus be assumed at 25,000,000, the elongation of a bar of wrought iron for a strain of 1000 lbs. per square inch will $= \frac{1000 \times 1}{25000000} = .00004$, for a unit of length. The linear expansion by heat of wrought iron for 100° F. $= .0007$, therefore it will require $\frac{.0007}{.00004} \times 1000$ lbs. $= 17500$ lbs. per square inch to elongate a bar of

wrought iron the same amount as it would expand by an increase of temperature of 100°. In other words, if a bar of wrought iron be rigidly held at its ends so as to be just taut but without strain, and it be then cooled off 100°, it will thereby be strained 17,500 lbs. per square inch. In the same manner it will be found, that if it be cooled off 150°, it will be strained 26,300 lbs.; and if 180°, 31,500 lbs. per square inch.

The wooden members, aA, AB and Bb will be considered unaffected by temperature, and it will be assumed for the present that they, the lower chord ab, and the main tie Ab, are of such large section compared with that of the counter tie Ba, that any strain in this latter member will not appreciably change their lengths. The lines $A_1\ B_1\ b_1\ a$, represent the contracted form of the figure at low temperature if all the members were of iron, and $AB_2b_2\ a$, the actual form it will assume under the conditions as they are and the assumptions we have made. The length of the counter tie, instead of being $=aB_1$ as it would be in an iron bridge where it is not strained by temperature, is stretched to the length aB_2. If the point B had not changed its position, the counter tie would have been elongated the amount $B_1\ B$, and it would then have been strained to the values given above, corresponding to the condition of a bar held fixedly at ends. By being stretched to B_2, it will be strained as much more than these values as B_1B_2 is greater than $B_1\ B$, granting that $aB_1\ B_2$ may be considered$=aB_2$. As the change of angles is very small, this approximation is admissible; and we may also assume that $B\ B_2$ and b_1b_2 are vertical straight lines.

Then, for the condition $h=d$, $BB_1=1.41\times b_1b$, $B_1\times b_1b$, $B_2=2.24$

and therefore $\frac{B_1B_2}{BB_1}=1.59$,

and for the condition $h=2d$ $BB_1=2.24\times b_1b$, $B_1B_2=4.12\times b_1b$,

and therefore $\frac{B_1B_2}{BB_1}=1.84$.

That is, if the depth of truss=the panel length, the values found above for the strains in a bar held fixedly at ends, will be increased 59 per cent., and if the depth of truss=twice the panel length, they will be increased 84 per cent.—therefore

Strains produced in counter tie in lbs. per square inch by a lowering of temperature :

For 100° F.	27,800	for $h=d$		32,200	for $h=2d$
" 150° "	41,700			48,300	
" 180° "	50,100			58,000	

Of the counter ties in a truss, those in the panels nearest the abutments are in the least favorable position as regards temperature strains. For them the assumption made, that the chords and the posts which enclose the panel are not changed in length by the increased strain in the counter, is approximately correct, and the section of the main tie to that of the counter is for ordinary cases, say a 150′ span, some such proportion as 6 to 1. Since the main tie will itself stretch in resisting the elongation of the counter inversely as its area is to that of the counter, and will reduce the strain in the counter a proportional amount, the above values would have to be reduced 1-7th to obtain the actual strains in counter for this case. If the panel is in the middle of the truss where both diagonal ties are equal in section, the strain by temperature would only be one-half the above values, and they would further be reduced by an appreciable shortening in length of the posts under the increased strain. There may be also a further reduction of the strain in the counter ties due to the contraction of the timber itself with the lowering of the temperature, but it is doubtful whether any allowance is to be made for this. Joule, the authority cited by Rankine on this subject in his "Applied Mechanics," gives a contraction in length for dry deal along the grain equal to about one-third that of bar iron, but states that he found moisture to diminish, annul, and even reverse the expansibility of timber by heat.

When it is considered that counter ties are almost invariably screwed up by bridge men on railroads—instructions to the contrary notwithstanding—so tight that they have an initial strain even at low temperature, and that the elastic limit of wrought iron is already reached at about 30,000 lbs. per square inch, enough will have been said to show that counter ties will be injuriously overstrained in combination bridges, and that their use should therefore be prohibited. It might be urged that, by some arrangement for locking the sleeve-nuts, the counters could be so adjusted as to avoid temperature strains, but they would then be so slack at low temperature that the jar occasioned by being pulled taut every time a train is passing over the bridge, would be a serious objection.

While the Howe truss is not free from temperature strains, they are not of so serious a character as in the combination quadrangu-

lar bridge, since the worst case in the Howe truss corresponds to the middle panel of the combination bridge, where, as we have seen, the values of the temperature strains first found were reduced more than one-half.

In the combination bridge of the Warren type, those braces near the middle of the truss which are subject to both tensile and compressive strains, should always be made of iron. The truss will then be free from temperature strains. Owing to the differences in the expansion of the iron and wood members, will assume a slightly greater camber in winter than in summer; and in consequence of the shrinkage of the timber in seasoning, it will settle down to a somewhat smaller than the original camber after the timber has had time to dry; but none of these slight changes in length will create strains, since the truss is free to accommodate itself to them.

DESCRIPTION OF DESIGNS.

The two plates which accompany this paper exhibit designs for a through combination bridge of 12 panels length, or say 168′ to 190′. Plate No. 1 represents a combination bridge with iron floorbeams and all web braces except the first or end brace of iron, and plate No. 2 a combination bridge with wooden floorbeams and the first and second braces of wood, *i. e.*, all those truss members of wood which are strained solely in compression. The former plan is more expensive in first cost than the latter, but furnishes decidedly the better bridge, and in the end the more economical one. There are two objections to wooden floorbeams; first, they must be made of very large sticks of exceptionally good and strong timber, and secondly, it is difficult to replace them in the bridge when decay sets in. In order to reduce the bending strain in the floorbeams as much as possible, the stringers must be placed 12′ apart between centres, but even then it requires two sticks, 8″x18″, of long-leaf yellow pine for a panel length of 14′, to carry, with a factor of safety of eight, (=1000 lbs. fibre strain per square inch,) an engine weighing 72,000 lbs. on a wheel base of 12 feet, notwithstanding long-leaf yellow pine is 50 per cent. stronger than white pine. Such large sticks of sound timber are scarce; in most localities they are very expensive now, and will rapidly become more so; and there is always some possibility that they may be unsound inside while showing no surface indications of it. The lateral rods being connected to the

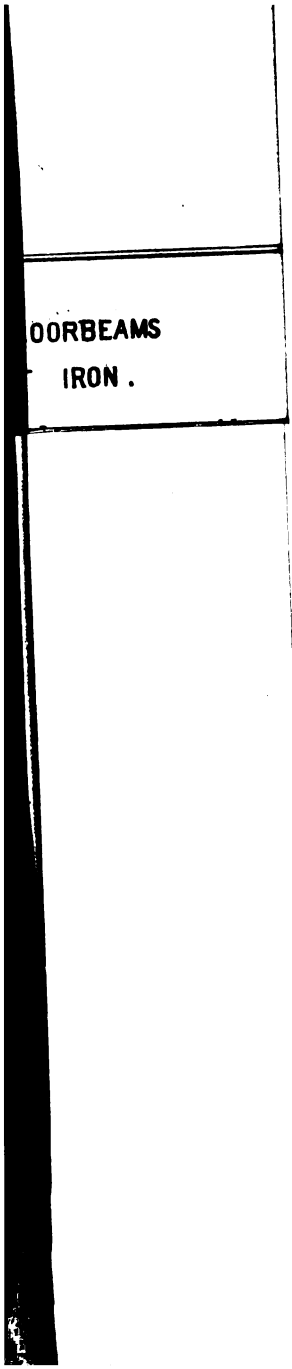
floorbeams and these hanging suspended from the lower
underneath the stringers and track, the floorbeam timber
most difficult to replace of any timber in the bridge, while
same time it is the first to decay, and suffers most by loss of st
from decay.

If the floorbeams are of iron, the lower lateral system need
disturbed while the timber is replaced, and the work of rep
can be easily, safely and rapidly done, no matter how unfav
the conditions may be. If, in addition, all the intermediate
braces are made of iron, so that only the first or end braces, th
chords, and the light vertical posts are of wood, a further grea
vantage is gained: the bridge may then be converted into
wrought iron bridge of the most approved pattern, with the gre
ease and with very little waste of the old material. The floor w
remain unchanged, except that iron I beams would be inserted in
of the wooden stringers; the lower lateral system, the lower ch
and the web braces would all remain untouched; the wooden v
cal posts would be dispensed with; the cast iron bolsters woul
displaced by wrought iron ones, and wrought iron end braces
top chords substituted for the wooden ones; the old cast joint b
would be thrown out and new pins of a length to suit the new
work provided, and the old Howe truss wind bracing between
chords replaced by new, all iron bracing. It will be seen that
new iron work is complete in itself, and connects with the old
work solely through the top chord and the end bottom chord p
A combination bridge of this kind, therefore, after having done
vice for eight or ten years until the timber requires displacing,
be converted into an all wrought iron bridge, losing only the c
ings, the top chord pins, and the top lateral rods by the change.

The design for wooden floorbeams shows longitudinal or strut r
running from floorbeam to floorbeam parallel to the centre lines
the trusses. These rods are designed to transmit the longitudi
component of the stress in the lateral rods from the free suspend
floorbeams to the next fixed floorbeams, the fixed floorbeams bei
those at the foot of the braces. The arrangement adopted for
design with iron floorbeams is, I think, preferable, and can also
applied to wooden floorbeams.

THE COST.

The advantages of the combination bridge over the Howe tru
having been pointed out, the important element of cost remains to
be considered.



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In order that the comparison be fair, the same factor of safety and quality of materials and workmanship must, of course, be assumed for both. Unfortunately, Howe truss bridges are so frequently built deficient in strength and, at least as regards the iron, of most inferior material, that it is commonly supposed they are much cheaper than they are found to be when properly constructed. It may be claimed as an advantage in their favor that any good bridge carpenter can build them, provided he buys the rods, the castings and the timber; but this advantage has practically had the result, that in very many cases the bridge carpenter does not simply build the bridge from detail plans furnished him, which is all he is competent to do, but he is entrusted with its construction without plans, and expected to proportion and design it himself. This becomes particularly hazardous when he acts in the capacity of contractor, and the promptings of pecuniary gain are added to his ignorance.

While wood possesses, among many defects, the estimable and redeeming quality of frequently giving warning of weakness if overstrained, by its outward appearance, it does not do this under all conditions, and in a Howe truss the iron rods are as essential to the safety of the structure as are any of the members of an iron bridge. It is therefore a very erroneous idea, though quite a popular one, that Howe truss bridges do not require that attention and regard for safety which iron bridges do.

The following table gives the quantities of materials in Howe truss and combination bridges, and their cost without erection based upon detail bills of material prepared for the different spans and the different kinds of bridges considered. A few approximate prices are added for iron bridges with wooden stringers, in order that a comparison may be made with them also. The 75′ and the 124′ spans are proportioned for consolidation engine loads, (engine and tender weighing 161,200 lbs. over a wheel base of 45¼ feet,) the 147′, 168′ and 210′ spans for a rolling load=2500 lbs. per foot of bridge; hence the first two spans should not be compared with the latter three. The span lengths and assumed loads were chosen so as to make some old estimates, prepared for a different purpose, which I had on hand, available, and thereby reduce the labor connected with the preparation of the table. It was, of course, of importance only, for the purpose in view, that the same spans be calculated on the same basis. The timber is assumed to be long-leaf yellow pine, except the cross-ties, which are estimated of oak. The prices are

those ruling several months ago; for iron they are Pittsburgh prices with 20 cents per 100 lbs. added to cover transportation charges; and for yellow pine they are those of the Alabama Lumber Association, with $12 per M. feet added on the same account. The location of the bridges corresponding to these freight rates may be assumed in the neighborhood of Louisville or St. Louis. The oak is estimated to cost $18 per M. feet on the ground. Pittsburgh prices for the cast iron in the Howe truss bridges were assumed at 2.8 cents per lb., and for the cast iron in the combination bridges at 3.3 cents per lb., and the average prices for wrought iron in the 168′ spans were as follows:

5.26c. per lb. for Howe truss with wooden clamps,

5.65c. per lb. for Howe truss with iron clamps,

5.69c. per lb. for combination bridge with wooden floorbeams and wooden compression braces,

5.65c. per lb. for combination bridge with iron floorbeams and iron second compression braces.

The yellow pine averages $31.50 per M. feet for the last named combination bridge, and $35 for the Howe truss, delivered.

The following are the maximum unit strains on which the estimates are based :

Iron in tension, 10,000 lbs. per square inch,

Iron in compression in the form of pin bearing braces, $\frac{8000}{1+\frac{l^2}{18000r}}$,

(l representing the length and r the least radius of gyration,) and in compression by bending or cross strains 8000 lbs. per square inch.

These units correspond to a factor of safety of 5. To allow for impact and vibration, additions were made to the rolling load of 25 per cent. for the iron floorbeams and the vertical suspension bars, and 50 per cent. for the floorbeam hangers.

Timber under cross strains and in direct tension is strained to 1000 lbs. per square inch, and in compression to $\frac{1000}{1+\frac{l^2}{d^2}\times.002}$ if square bearing, d representing the least side, and $\frac{1000}{1+\frac{l^2}{d^2}\times.004}$ if pin bearing, no allowance being made for impact.

As Howe truss bridges are now seldom built with wooden clamps for splices in the bottom chord, iron clamps making a much better connection, it would be proper to compare the cost of the combination bridges only with the cost of the Howe truss bridges built with iron clamps; but I have thought best to include also the Howe truss with wooden clamps in the comparison, in order to show that even this, the cheapest form of wooden bridge, compares unfavorably with the combination bridge in point of economy. A further assumption in favor of the Howe truss bridge is made, in that the keys are estimated of wood for it, and of iron for the combination bridge.

Comparative Statement for Howe Truss and Combination Through Bridges, Showing the Materials Required, and the Cost, Exclusive of Erection.

Length of Span.		Howe Truss Bridge.		Warren Combination Bridge.		
				Floorbeams of Wood.		Iron floorbeams.
		With wooden clamps and wooden keys.	With iron clamps and wooden keys.	All compression braces of wood.	All braces except end braces of iron.	All braces except end braces of iron.
75 ft. Heavy rolling load.	Panel length	10.7 ft.	10.7 ft.	12.5 ft.	12.5 ft.	12.5 ft.
	Depth	23 "	23 "	22 "	22 "	22 "
	Wrought iron	10,050 lbs.	10,780 lbs.	14,160 lbs.	14,160 lbs.	22,600 lbs.
	Cast iron	6,680 "	7,970 "	6,190 "	6,190 "	4,810 "
	Yellow pine	25,680 ft.	25,680 ft.	11,250 ft.	11,250 ft.	8,680 ft.
	White oak	3,180 "	2,900 "	4,550 "	4,550 "	4,550 "
	Cost per foot of bridge	$21.00	$22.30	$19.40	$19.40	$24.25
124 ft. Heavy rolling load.	Panel length	10.3 ft.	10.3 ft.	15.5 ft.	15.5 ft.	15.5 ft.
	Depth c. to c. chords	23.5 "	23.5 "	24 "	24 "	24 "
	Wrought iron	23,870 lbs.	26,550 lbs.	29,830 lbs.	36,850 lbs.	48,700 lbs.
	Cast iron	16,610 "	20,760 "	10,000 "	9,500 "	7,570 "
	Yellow pine	48,270 ft.	48,270 ft.	22,300 ft.	20,430 ft.	16,830 ft.
	White oak	5,670 "	4,870 "	8,720 "	8,720 "	8,720 "
	Cost per foot of bridge	$28.20	$31.00	$24.30	$27.10	$30.60
147 ft. Light rolling load.	Panel length	10.5 ft.	10.5 ft.	14.7 ft.	14.7 ft.	14.7 ft.
	Depth c. to c. chords	23.5 "	23.5 "	25 "	25 "	25 "
	Wrought iron	29,250 lbs.	33,170 lbs.	40,320 lbs.	47,740 lbs.	62,940 lbs.
	Cast iron	19,430 "	24,510 "	13,000 "	12,120 "	9,640 "
	Yellow pine	59,740 ft.	59,740 ft.	25,940 ft.	23,430 ft.	18,810 ft.
	White oak	6,800 "	5,750 "	8,840 "	8,840 "	8,840 "
	Cost per foot of bridge	$29.20	$32.45	$25.55	$27.90	$32.20
168 ft. Light rolling load.	Panel length	10.5 ft.	10.5 ft.	14 ft.	14 ft.	14 ft.
	Depth c. to c. chords	23.5 "	23.5 "	26 "	26 "	26 "
	Wrought iron	38,750 lbs.	43,730 lbs.	61,950 lbs.	71,650 lbs.	90,240 lbs.
	Cast iron	25,820 "	31,760 "	15,680 "	14,820 "	11,790 "
	Yellow pine	74,790 ft.	74,790 ft.	32,020 ft.	29,320 ft.	23,670 ft.
	White oak	7,870 "	6,640 "	9,980 "	9,980 "	9,980 "
	Cost per foot of bridge	$33.60	$37.15	$32.00	$34.90	$39.35
210 ft. Light rolling load.	Panel length	10 ft.	10 ft.	15 ft.	15 ft.	15 ft.
	Depth c. to c. chords	28 "	28 "	28 "	28 "	28 "
	Wrought iron	76,520 lbs.	83,600 lbs.	95,840 lbs.	105,740 lbs.	127,740 lbs.
	Cast iron	47,100 "	55,250 "	23,510 "	22,220 "	18,640 "
	Yellow pine	120,690 ft.	120,690 ft.	51,810 ft.	48,770 ft.	42,090 ft.
	White oak	10,960 "	9,200 "	14,090 "	14,090 "	14,090 "
	Cost per foot of bridge	$47.70	$57.45	$40.05	$42.25	$46.10

The cost of a 147 ft. span in iron with wooden stringers on the above scale of prices is $47.50 per foot approximately, and of a 168 ft. span, $52.60 per foot approximately.

The combination bridges with iron floorbeams have been estimated of the same panel length as the combination bridges with wooden floorbeams, in order to avoid the necessity of making new calculations and estimates entire for the bridges on this plan. The panel lengths should have been increased, and the cost of the combination bridge with iron floorbeams would then have appeared lower than it does. Making allowance for this, the table shows,

1st, That the cheapest form of combination bridge (with wooden floorbeams and wooden compression braces) is cheaper than the cheapest form of Howe truss bridge (with wooden clamps);

2dly, That the combination bridge with wooden floorbeams and intermediate braces of iron is still cheaper than the same form of Howe truss, or at least as cheap; and,

3dly, That the best form of combination bridge (with iron floorbeams and iron intermediate braces) is as cheap as the best form of Howe truss bridge (with iron clamps).

These results are very surprising at first glance, but a study of the table, and the following considerations, will afford the necessary explanation:

In the combination bridge the panel length may be as long as the wooden stringers or wooden floorbeams will permit. A convenient length for the former, and one which will not require the sticks to be over 16″ deep, is 15′. In the Howe truss bridge the bottom chords have the double duty to perform of carrying local loads to the panel points—the wooden floorbeams being laid directly upon the chords—and of acting as truss members. To the direct tensile strains are added, therefore, cross or bending strains, and it is generally necessary to reduce the panel length to about 10′, in order to keep within practicable limits in the sizes of the timber. It has already been shown that there is much waste of timber in the bottom chords owing to the difficulties in the way of splicing the timber, the sticks joined having to be neglected in calculating the effective chord section. To this item of extra cost is now to be added the extra material required in the web by the use of short panels, on account of the greater number of braces, of rods, and of castings. The table shows that there is two to three times as much timber required in the Howe truss as in the combination bridge, and, owing to the lengths and the large sizes necessary for the bottom chords, the timber is more expensive per M. feet. The joint boxes in the top chords of the combination bridge

occur only every 30′, and very little cast iron is necessary in the bottom chords. As a result we find the cast iron required for the Howe truss bridge 50 to 100 per cent. in excess of that necessary for the combination bridge. The wrought iron being used to great advantage in the combination Warren bridge, the increase in this item is comparatively small. The bottom chord bars are 30′ long, and there is therefore little loss through frequency of joints; and the web members act at a favorable angle. In consequence, the wrought iron in the cheaper form of bridge with floorbeams and compression braces of wood, is at most only 60 per cent. greater than in the Howe truss.

The table of cost does not include erection. If this item had been considered, the showing would have been still more favorable to the combination bridge, the latter requiring less and simpler framing. But it was my purpose, less to show how much cheaper combination bridges are than Howe truss bridges, than to establish that they compare so favorably in first cost with the latter, that, in consideration of their many superior merits, there can be no question to which preference should be given. Attention has been called to the advantages of iron floorbeams over wooden ones. The table shows the increase of cost to average about $4 per lineal foot, and I cannot conceive of any conditions which would not justify this additional expenditure, and also the extra cost of making the intermediate web braces of iron, leaving only the end braces and the top chords of wood.

By far the greater number of bridges built are through bridges, and in these remarks I have not thought it necessary to treat specially of the combination deck bridge, because it does not present peculiar features of its own. It should be said, however, that iron floorbeams in its case do not offer the special advantages which they possess in the through bridge, because the trusses in the deck bridge are usually placed nearer together, and extreme sizes of timber are not required for wooden floorbeams. They are also easily replaced, and the lateral bracing is usually made to connect with the chords and not with them.

COMPARISON WITH IRON BRIDGES.

Two objections to the use of timber for constructive purposes, its perishable nature and the uncertainty of its strength within wide limits, have been mentioned. They have not received considera-

tion thus far, because they have no bearing on a comparison of the Howe truss with the combination bridge, both making use of this material. But they are weighty considerations in comparing the modern iron bridge, built entirely of wrought iron, with the combination bridge, for the advantages of the one over the other are due entirely to the difference in the qualities of the materials employed; it is wood pitted against wrought iron, and cast iron against wrought iron.

Cast iron in combination bridges is used in the form of joint boxes, in the same manner as it was generally used in the older iron bridges in this country, and is still employed in modern bridges with closed cylindrical form of compression members. These joint boxes are made heavier than the strains to which they are subjected would call for, and by observing ordinary precautions and employing good material they can be made safe. But cast iron never offers that guarantee of security which wrought iron does. Its process of manufacture is never so sure of good results as that of wrought iron, and while the latter material will bend and stretch under abuse long before it will break, the former is unyielding and gives way suddenly and without warning.

Wood is subject both to decay and to destruction by fire. Its durability in bridges exposed to the weather varies very much with the kind of lumber and the locality—ordinarily requiring renewal after eight years—and the danger from fire is a serious one. Both as regards fire and decay the combination has the advantage over the Howe truss bridge, in that the quantity of timber is very much reduced, and is used in such form as to admit of being readily protected from the weather, as by the sheet iron covering shown on plate No. 1, whereby its durability is much increased and the danger from fire lessened. Whether it will pay, and be otherwise desirable, to treat the timber by some process which, besides preserving it, will also render it incapable of catching fire, I am not prepared definitely to say. In order to answer this question it will be necessary to make tests of treated lumber and ascertain what influence treatment has upon its strength. I had hoped to include in this paper an exhibit of such tests, but owing to unforeseen delays in obtaining the materials, the tests could not yet be made.

As is well known, timber in direct compression, as the top chords and the compression braces in trusses, is proportioned like iron by either Gordon's or Hodgkinson's formula. These formulæ contain

constants, the values of which must be obtained from the results of actual experiments. A very limited number of such experiments on timber pillars have been made, but the results differ so much that no dependence can be placed on any formula now in use. Future tests, which are sorely needed, will no doubt dispel much of our present ignorance, but the difficulty is one partially inherent in the material itself, and is the result of actual variations in the strength of the same kind of timber. The endless variety of conditions which affect the growth of timber in the tree are also of influence on its strength when cut. They come under the general heads, the climate, the locality, and the soil. The age of the tree, and the greater or less freedom of the timber from defects, such as knots, sap, and windshakes; the straightness of the grain; and last, not least, the degree of seasoning it has received, are of the greatest importance. The last condition alone may affect its strength 100 per cent., well seasoned timber being sometimes of double the strength of green.

Wrought iron exhibits none of the faults and defects last mentioned. Its quality is easily controlled, its strength readily ascertained; there need be no uncertainty about either. It is therefore safer, and it has the great value of permanency. These advantages cannot be estimated in money, and railways with heavy traffic cannot afford to do without them. But the cases of the application of a cheaper substitute for the iron bridge are innumerable. Many railways have so small an income that they can only look to present saving irrespective of ultimate economy; and new enterprises can frequently command only the means to complete a line of railway on the cheapest plan possible, having to look to future earnings for improvements. The combination bridge on the plan proposed possesses all the advantages of the iron bridge, so far as the materials of which it is constructed will admit, and it can only be a want of knowledge of its merits and capabilities, when properly designed and built, and the idea that it is expensive, which have thus far prevented it from taking the place of the Howe truss and becoming the only substitute for the iron bridge.

ANNUAL REPORTS.

JANUARY 18, 1881.

ADDRESS OF THE RETIRING PRESIDENT, WILLIAM METCALF.

Gentlemen of the Engineers' Society of Western Pennsylvania:

A little over a year ago several gentlemen discussed the propriety of organizing a local society of engineers, for the purposes of better acquaintance and interchange of ideas.

It was supposed that about twenty or thirty engineers could be got together, and that probably as many more persons, not engineers, might be induced to join, just to help the movement.

Small, pleasant meetings, an occasional paper, and a good deal of friendly intercourse, were about all that was expected to be accomplished by the projectors.

On December 18, 1879, a preliminary meeting was called, and 40 persons were present; it was decided unanimously that we ought to organize.

On January 6, 1880, 32 gentlemen met, adopted a constitution and by-laws, elected officers, and our Society was organized.

Since that time our membership has increased to 184, and, to the surprise of every one, it has been observed that the larger part of these are either civil or mechanical engineers, so that we are in fact, as well as in name, a Society of Engineers.

The very full and able report of the Secretary leaves but little to be said, yet the statistics given deserve some further notice.

There have been eleven general meetings of the Society, with an average attendance of 51; and although there has been a slight falling off in numbers at the last three or four meetings, this is not to be wondered at when we consider the excitements of a Presidential election and the engagements of the holiday season; these past, it is believed that the active interest in the meetings will increase.

Twelve papers have been read at the meetings, and it may be said of them, in general, that their character has been high; some have been re-published in periodicals in this country and in Europe, and while we ought to feel gratified at the wide extent and large number of exchanges reported by the Secretary, yet we need have no fear of being made to blush for our own productions.

All this is truly gratifying to our self-love, yet for our own good there is room just here for a little self-criticism.

What we need for our own benefit, and indeed, gentlemen, what we must have, if we are to hold together and keep up the interest in our proceedings, are more short, informal papers, more of such admirable relations of our own experiences, as that to which Mr. Diescher treated us, and more of free discussions and less of formality.

Allow me to say, gentlemen, that you are the best behaved set of gentlemen that any one ever presided over. More than fifty of you at every meeting, and each meeting extending through two or three hours, and not once has the presiding officer had a chance to assert his authority; not once has the gavel fallen in just indignation at some breach of decorum, either in speech or manner; not once has even an august presidential frown been necessary to quell some rising disturbance.

This is all very admirable; harmony is perfectly lovely; but we ought not to be quite so solemn about it. You display the well known modesty and retiring manner of the average engineer to such perfection that you are really in danger of making your proceedings dull. This is not fair to the presiding officer; it does not give him a chance to wield the power which he prizes so highly. You will remember that this is the address of the retiring President, and that he is now speaking for the benefit of his successor. But, seriously, this over-formality or over-modesty in our meetings is all wrong.

A member spends much time and care in preparing an admirable paper; he is listened to with interest, duly applauded when through, and takes his seat, expecting an interesting discussion, and has crammed himself, ready to answer every question.

An awful pause ensues, and then follows a series of flirtations between the chair and the over-modest members, the chair coaxing and making sheep's eyes all over the vast assembly, and the coy ones all holding down their heads and listening.

This is not always so; we have had some very lively, very intelligent, and very interesting discussions; and such we ought to have at every meeting. These remarks would not be fair if it were not a fact that often these silent ones were fairly exploding with questions, objections and arguments, and no sooner is the magic word "adjourned" pronounced than the air fairly resounds with this bottled-up intelligence, which the whole meeting ought to have enjoyed.

Excuse the length of this scolding—it is the last chance of the present incumbent, and truth compels the remark that it is the first opportunity he has had for grumbling during the whole year. What the meetings need to make them perfect, is a little more of an easy and social character in our discussions.

It is a cause for real congratulation that our finances are in such good condition. The usual mode of procedure in new societies is for a few people to get together, organize, run up a big debt, and then run all over the community coaxing everybody to join, so as to help to pay off the debt. Fortunately we have no debts, every obligation has been met, our papers have all been neatly published but one, and that would have been published and paid for, but the author is too busy to write it.

We have a cash balance for the year of $9.15, and about $140 of unpaid dues. The 28 members who have not paid are, of course, mostly the newly elected members, who have not had a chance to pay.

Everything has been done as neatly as our means would allow, and your Board of Directors have been careful, in the use of your funds, to avoid all extravagance.

And now, gentlemen, the dues for 1881 are due, and every member should be careful to pay up promptly, so that the incoming Board may have no embarrassment. It would be well to remind members just here, that our small annual dues include full membership in the Mercantile Library Association, with all of its privileges; that all of the rent we pay is expended for technical works for the Library; that a committee of our Society is consulted in the purchase of the books; and that the Library Association have just ordered a long list of technical periodicals suggested by us, which will soon be

found on the Library tables for the use of all. A more liberal or large-minded arrangement it would be difficult to imagine. The Library Association very kindly say they are glad to have us here, and we can as truly say we are glad to be here, and we believe the arrangement will be of great advantage to both societies; we certainly have been treated with the utmost consideration and courtesy.

Our excursion last summer was most charming. You know we adjourned for three months that we might enjoy it. Your Board worked at it faithfully nearly the whole season; in fact, one member of the Board gave up all of his other summer holidays to this one. We went down the Ohio to West Virginia, through that State to Virginia, visiting all of the most celebrated mines and fashionable watering places we could find, and returned by the way of Washington. It is unnecessary to tell you anything about what we saw, for our next paper, by Mr. Weeks, is to be a description of that very country. To be sure, only the Board went on that excursion, and went at the expense of the Society; but the members who were left behind need not complain, for the whole cost of the trip was only about $1.00. The incoming Board promise to make a shorter excursion this year, and to take everybody along. In fact, that is about the only issue in the coming election.

The arrangement with the Library Association, and their agreement to spend the money received from us for technical books, led to the organization of our Library Committee. Your committee took up the subject thoroughly, and soon found that there was nothing in the city that could be called even the beginning of a technical library.

When we consider the vast industries of our city, and the large number of permanent and of transient engineers, whose services are constantly required by those who conduct our immense manufactures, it is amazing that there should be absolutely no library for those engineers to consult. This great want your committee determined to begin to supply, by buying a good foundation with the small fund at their disposal, $400. But it was soon found that that sum would hardly lay a corner-stone. Lists of books were carefully prepared, and it was found that the fund would hardly do to begin on. An appeal was made, and through the munificence of Mr. Wm. Thaw, who gave $1000, and other friends, the sum of $2000 has been secured, which, in addition to the $400 of the Library Association, will enable us to make a respectable beginning. The Library

will be one of reference only; the utmost care will be exercised to secure only the best works, and they will be here for the use of the members at all times. Any books especially donated to our Society, or any funds given us, will be expended for books, which will be stamped with our seal and will be our property.

The Library Association will give us shelf-room for our own books, which will be available for use by all members of both societies, but only for reference; the members of neither society will be allowed to take the books out of the library rooms.

Now, gentlemen, your Library Committee needs the assistance of every member of the Society; it wants money from those who can and will give; it wants books from those who have them to spare; and it wants suggestions from those who can give them as to the proper books to buy. It wants beggars—unmitigated beggars; it wants every one to write to every unfortunate author he happens to know, and ask him for a copy of his works. Dozens of begging letters have been written already, and dozens more ought to be written by every one of you. We want reports of works, of surveys, and of every engineering project on which a report has been written.

Here is a grand opportunity to do a good thing, and for everybody to work at it.

Your committee do not intend to spend one dollar of their two thousand until every possible resource of begging has been exhausted, so that they can have as much money as possible to spend on the more expensive works which we cannot hope to have given to us.

With the active aid of all, we ought to have within three months at least 1000 good, valuable works. It is to be hoped that every member of the Society will find time to do something to make our Library of real value.

It has been our painful duty, during the year, to announce one death of a member—Mr. Andrew Kloman. Mr. Kloman was essentially a man of the people; having begun life as a mechanic, and raised himself to high rank among our mechanical engineers, he never ceased to be a thorough and accomplished mechanic. Simple in all of his ways, and direct in his methods, he never failed to do, and to do well, any work which he undertook.

Modest and unassuming as a child, he was never known to boast of what he had done, yet his mind was a perfect treasure-house of valuable information, which he was ever ready to pour out without

stint when he was asked for counsel. Kind-hearted and gentle, his friends always turned to him with pleasure, for he was sure to be in good humor and to shed a pleasant atmosphere all around him.

Industrious to such an extent as to have worn himself out, when his most intimate friends looked upon him as in the prime of life and of manly vigor, he was never flurried, never in a hurry, and always had time to give an attentive ear and a helping hand when called upon.

He was one of nature's noble men, an ornament and a credit to our city, and his departure is a great loss to all of us. Such a life is an example well worth study and emulation. It should teach every young mechanic the possibilities of a future to be gained by well-spent effort; and it should teach every young man that a mechanic may be a gentleman, may become eminent as an engineer, and may prove his title to rank with the best and the noblest in the community.

It ought to teach thousands of our misguided youth that the sure road to high character, substantial success, and thorough independence, runs straight through the workshop, and not through the office.

A fitting memorial of Mr. Kloman's life will be prepared by a committee for preservation in our proceedings.

And now, gentlemen, what does each member owe to this Society? He owes some little thought and time to the consideration of what he can do to help. He can come to the meetings when not really hindered by more pressing matters. When here he can take an active interest in the proceedings, and he ought to take an active part in the discussions. If he does not know anything, he can ask questions and so inform himself. But he does know something, everybody knows something, and that thing he ought to tell; that is what we come here for. He can influence some one to join our Society, and so increase our means and our strength. He can pay his dues promptly, and if that be done we can not only keep out of debt, but we can add the necessary wood cuts, so as to have our Transactions published as completely as they ought to be, and will be, if you provide the means.

It would be improper to close without a few words as to your officers.

Your Board has held many meetings, has considered the interests of the Society carefully, and has expended your money judiciously.

Your Treasurer has held a tight grip upon the purse strings, and has allowed nothing to go out improperly; it is to be regretted that he declines to serve you longer.

Your Secretary has discharged the many duties of his place carefully and cheerfully. The records and minutes are complete and orderly, and you are to be congratulated upon having put the right man in the right place the first time you tried.

Finally, the Chair begs leave to thank you most heartily, not only for your patient attention this evening, but for the extreme courtesy and indulgence which you have shown through the whole year.

REPORT OF THE SECRETARY.

To the Board of Direction of the Engineers' Society of Western Pennsylvania:

GENTLEMEN:—I have the pleasure to submit the following report for the year ending January 18, 1881. As this is the first year of the Society, it may be well to review more in detail than would otherwise be necessary.

December 18, 1879, a preliminary meeting of the engineers of Pittsburgh and vicinity was held in the office of the City Engineer of Pittsburgh, to take such action as was deemed best in relation to the formation of an engineers' society. At this meeting there were forty present. After discussion as to the necessity of such a society, a committee was appointed to draft a constitution and by-laws. This committee reported, and after discussion and amendment ordered to be printed, and final action deferred until January 6, 1880.

January 6, those present at the last meeting met in the Council room, Pittsburgh; 32 present. After discussion and amendment the Constitution and By-Laws were passed finally. The name of the society to be the Engineers' Society of Western Pennsylvania.

Officers were then elected to serve for the ensuing year:

Wm. Metcalf, President,	term expires	Jan. 18, 1881
A. Gottlieb, Vice Pres't,	"	Jan. 17, 1882
J. I. Williams, Vice Pres't,	"	Jan. 18, 1881
Wm. Kent, Treasurer,	"	Jan. 18, 1881
J. H. Harlow, Secretary,	"	Jan. 18, 1881
N. M. McDowell, Director,	"	Jan. 17, 1882
J. L. Lowry, "	"	Jan. 17, 1882
T. Rodd, "	"	Jan. 18, 1881
E. M. Butz, "	"	Jan. 18, 1881

January 20, 1880, was the first regular meeting of the Society, the regular meetings being held the third Tuesday of each month.

Meetings have been held every month since January 20, except June, July and August.

The membership and attendance at the regular meetings have been as follows:

	Membership.	Present.
January 20, 1880	110	56
February 17, 1880	126	59
March 16, 1880	140	67
April 20, 1880	159	70
May 18, 1880	164	—
September 21, 1880	176	41
October 19, 1880	185	35
November 16, 1880	190	44
December 21, 1880	190	40
Average attendance		51

The number of members and the high average attendance shows that such a society as this is needed here.

The following papers have been read during the year:

Jan. 20. Why does Steel Harden? By Wm. Metcalf. Description of a Derrick used at Davis Island Dam. By J. H. Harlow.

Feb. 17. The Allegheny River. By Thomas P. Roberts.

March 16. The Tay Bridge. By A. Gottlieb. The Metric System. By Wm. Kent.

April 20. Constitution of Earths and Slips in Clayey Soils. By Lieut. F. A. Mahan. Steel in Construction. By Albert F. Hill.

May 18. The Metric System. By Lieut. F. A. Mahan.

Sept. 21. The Danks Puddling Furnace. By John I. Williams.

Oct. 19. Blasting. By Arthur Kirk.

Nov. 16. Mr. Samuel Diescher gave his experience with some slips on Brownsville avenue. This has not, as yet, been written out for publication, but the author promises to do so soon.

Dec. 21. The Basic Dephosphorizing Process; What it Is, and What may be Expected from It. By Jacob Reese.

All of the above papers have, with the exception of Mr. Diescher's, been published and sent to the members.

This Society has taken a promiuent position in the rank of local societies, and some of its papers have been in considerable demand. Requests for papers and exchanges have been received from Austria, Sweden, Portugal and Buenos Ayres.

The Society, in exchange for its publications, has received the following:

Transactions of the American Society of Civil Engineers for January, February, March, April, May, June, July, August, September, October and November, 1880.

Papers read before the American Institute of Mining Engineers since May, 1879.

Proceedings of the Engineers' Club of Philadelphia, Vol. I, Nos. 1, 2, 3, 4, 5, and List of Members, November, 1880.

Boston Society Civil Engineers' Constitution and By-Laws, List of Members and Minutes of Meetings, and Papers read since February 16, 1880.

Proceedings of the Civil Engineers' Club of the Northwest. Vol. IV, (bound).

Papers read before the Pi Eta Scientific Society, Troy, N. Y.

Proceedings of the Iron and Steel Institute for 1879–80.

Proceedings of the N. Y., P. & O. R. R. Road Masters' Meetings, November 13, 1879, to May 13, 1880.

From the Chief of Engineers, Report for 1879, and a large number of specifications of work let in 1880 by the various engineering officers, from Maine to California.

Improvement of the Danube at Vienna. Translated by G. Weitzel, Major of Engineers.

Hollow Brick Foundations, Arches in Masonry Bridges. By W. H. Bixby, Lieutenant of Engineers.

Report on Washington Monument.

Report of Mississippi River Commission.

Five Photographs illustrating Steel in Construction. By Albert F. Hill.

Proceedings of the Joint Publication Association, Cleveland.

Journal of the Society of Arts, London, weekly from April 2, 1880, to date.

Anales de la Sociedad Cientifica, Argentina, Buenos Aires, for April, May, August, September, October and November, 1880.

Ingeniors Foreningens Forhandlinger, Stockholm, four numbers, 1880.

Revistu de Obras Publicas e Minas Publicaçao Mensal du Associaçao das Engenheiras Civis Portugueses, for February, March, April, July, August, 1880.

A charter was granted the Society March 20, 1880. A seal has also been obtained. Arrangements were made with F. Woods, of the *American Manufacturer and Iron World* of this city, to publish all papers read before the Society in a form suitable for distribution among the members.

A committee, consisting of Messrs. Dempster, Williams and Reno, were appointed to urge upon Congress the reinstatement of the Iron and Steel Testing Board, and a report is expected at the annual meeting. A report from the Library Committee is also expected at this meeting.

During the early part of the year the Society, through the courtesy of the Western Iron Association, met in its rooms, but June 15, 1880, arrangements were made with the Pittsburgh Library Association, by the payment of $400 per year, for the use of the Art Gallery for nine monthly meetings, and for use of the library by members of this Society; the $400 to be expended by the Pittsburgh Library Association in conjunction with a committee of this Society in the purchase of scientific books and periodicals. Under this arrangement the following periodicals have been ordered, and may be found on the Library tables: American Architect and Building News; American Machinist; Engineering News; Engineering and Mining Journal; Railway Gazette; Railway Review; Scientific American and Supplement; American Engineer; American Gaslight Journal; American Journal of Microscopy; American Miller; Carpentering and Building; Eclectic Engineering Magazine; Journal of Chemistry; Journal Franklin Institute; Manufacturer and Builder; Milling and Mechanical News; Sanitary Engineer; Engineer; Engineering; Annales des Mines; Annales des Ponts et Chaussees; Annalen der Chemie Civil Engenieur (der); Journal fur Praktische Chemie; Polytechnisches Journal.

Eleven meetings have been held by the Board of Direction during the year, and considerable routine work performed.

The list of persons elected to the Society contains 190 names; 156 have paid dues and are full members, leaving 34 who have not paid as yet; 6 decline to become members, but the remaining 28 will probably soon settle their dues.

The receipts for the year have been:

156 members' dues for 1880	$780 00
Publication	14 00
	$794 00
The expenditures, as per bills approved, are	784 85
	$9 15
Two members' dues for 1881	10 00
Cash on hand	$19 15

There has been but one death in the Society during the year, viz., that of Andrew Kloman.

Messrs. James Park, Jr., and James Hemphill, have been appointed a committee to prepare a memorial.

Respectfully submitted.

J. H. HARLOW, *Secretary.*

TREASURER'S REPORT FOR THE YEAR ENDING JANUARY 18, 1881.

Receipts.

Dues from 156 members for year ending January 18, 1881	$780 00
Dues from 2 members for year ending Jan. 17, '82	10 00
For extra copies of Transactions	14 00
Total	$804 00

Expenditures.

Pittsburgh Library Association, for use of Library as per agreement, paid to April 15, 1881	$300 00	
Salary of Secretary, 1 year	200 00	
Commissions on collections of dues, 5 per cent. on $170	8 50	
American Manufacturer, for printing Transactions	102 00	
Stationery and postage	86 43	
Expenses of procuring Charter	30 00	
Designing and engraving Seal	45 00	
Rent of P. O. box and keys for same	9 92	
Paid Janitor of Hall	3 00	
Total		784 85
Balance in hands of Treasurer		$19 15

Respectfully submitted.

WM. KENT, *Treasurer.*

REPORT OF CHAIRMAN OF SUB-COMMITTEE OF LIBRARY COMMITTEE.

PITTSBURGH, PA., January 17, 1881.

Mr. Wm. Metcalf, President Engineers' Society of Western Pennsylvania:

SIR:—Having been requested, as chairman of the sub-committee of the Library Committee, to submit the report of the committee, I have the honor to state:

1st. That at two or three informal meetings of the sub-committee with the committee appointed on behalf of the Library, it was about decided that the most convenient place to set the scientific works purchased for the Engineers' Society, or for the Mercantile Library, would be the southeast corner of the Library. There are windows in both sides of this corner, and there would be the advantage of light and a certain degree of exclusiveness.

2d. That the various members of the Library Committee have been requested to furnish, each one, a list of books that he considered it would be well to purchase in the line of subjects entrusted to him. Almost all the members answered this request by sending in lists more or less extensive. These lists will have to be consolidated for more convenient reference. There are mentioned, in all, about three hundred and fifty works, which will give a fair start to the scientific alcove.

3d. That two subscriptions of $1000 each, one from Mr. William Thaw and one from another friend, have been devoted by these gentlemen to the exclusive use of the Engineers' Society. These subscriptions, it is hoped, may be succeeded by others, so that the Library of the Society may be soon such as it should be for the aims and professions of the members.

Very respectfully,

F. A. MAHAN,

Chairman Sub-Committee.

Committee on Testing of Iron and Steel had no report to offer.

After hearing the reports, Messrs. James Park, Jr., and Charles Ackenheil were appointed tellers to receive and count the ballots for President, Vice President, Treasurer, Secretary and two Directors. The following were announced as being elected:

Wm. Metcalf, President	Term to expire			Jan. 17, 1882
Thos. Rodd, Vice President	"	"	"	16, 1883
A. E. Frost, Treasurer	"	"	"	17, 1882
J. H. Harlow, Secretary	"	"	"	17, 1882
Samuel Diescher, Director	"	"	"	16, 1883
Francis C. Phillips, Director	"	"	"	16, 1883

Article III of the By-Laws was amended so as to read: "The dues of members shall be five dollars per annum, payable in advance at the annual meeting; Provided, however, that all members elected after the first day of July shall pay one-half of said amount, and receive the Transactions of the current year."

ANNUAL REPORTS OF OFFICERS.

JANUARY 17TH, 1882.

ADDRESS OF THE RETIRING PRESIDENT.

To the Members of the Engineers' Society of Western Pennsylvania:

GENTLEMEN:—It is a matter of real regret that I am obliged to be absent from our annual meeting.

In reviewing the past year, I see nothing but encouragement for the future.

The attendance at the meetings, averaging 46, is very remarkable, and shows a sustained interest in our proceedings which, I believe, is not equaled by any society in the country. A monthly attendance of over twenty per cent. of our whole membership shows a lively interest, which simply means that our Society is a grand success, and that it has filled a great want in our busy community.

I can say without flattery, that in the last two years I have frequently wondered where all of the members came from, and why they came together.

This only shows that the great growth of our city has not been properly realized by the natives, and that the need of friendly intercourse has, in consequence, not been provided for.

It is a matter of sincere congratulation that in the two years of our existence we have never had a meeting without a paper, and generally a good one, and sometimes very good ones; also, that we have never incurred any debt, and that we now have a balance in the treasury which will justify the incoming Board in having our Transactions printed in a little better form than before.

To be out of debt is to be successful, and I have no doubt that the new Board will manage as carefully in this respect as has the old one.

A Library of some three hundred volumes of carefully selected technical works, all paid for, is no mean achievement, and your Library Committee, now to be replaced by a permanent committee, deserves your regard for the large amount of work and care they have given to the selection of these books.

The reports of the Secretary, the Treasurer, and the committees on Library and Tests, will give you full information of the details of the work of the year.

It is a pleasant duty to bear testimony to the zeal, industry and care which have been used by the Secretary and Treasurer in conducting your affairs, and I feel it to be especially due to your Secretary, who has added to his ordinary duties those of Librarian and secretary of the general committees. To his unremitting attention, care as to details, and exactness in records, is largely due the success of the Society, the smooth running of its machinery, and the general good condition of your affairs.

The Board of Direction has met frequently, and has considered all of the business of the Society with great care, and the proof of this is in results; everything has been well done, and we "owe no man anything but to love one another;" and here is your greatest achievement: you have organized, held your meetings, pursued steadily the objects of the Society; many friendships have been formed; questions have been discussed freely and fully, and not one word of discord has entered our councils either in public or in private. Gentlemen, this is better than wealth or glory.

In retiring to the ranks of private membership, I do not know how to thank you for the unvarying kindness and courtesy with which I have been treated. I can only commend my successor to the same good will and indulgence, and I can only add that I mean to still be with the Society, and to work with all my might to make things as lively as possible, so that our worthy "God love" may never have a chance to go to sleep; and that we may all remain alert to our mutual interests is the best wish of

Your "retiring President,"

WM. METCALF.

REPORT OF TREASURER FOR YEAR ENDING JANUARY 17, 1882.

1881.	*Receipts.*		
Jan. 18.	Balance from Wm. Kent, Treasurer	$19 15	
	Dues from 5 members to Jan. 18, 1881, at $2.00	10 00	
	Dues from 6 members to Jan. 17, 1882, at $2.00	12 00	
	Dues from 5 members to Jan. 18, 1881, at $5.00	25 00	
	Dues from 186 members to Jan. 17, 1882, at $5.00,	930 00	
	Dues from 7 members to Jan. 17, 1882, at $2.50	17 50	
	Dues from 7 members to Jan. 16, 1883, at $5.00	35 00	
	For extra copies of Transactions	3 35	
	For P. O. keys returned	1 00	
	Total		$1,053 00
	Expenditures.		
	Mercantile Library Association, as per agreement, to March 15, 1882	400 00	
	Salary of Secretary, one year	200 00	
	American Manufacturer, for printing transactions	67 20	
	Postage and Stationery	47 00	
	Stenographic reports for the year	30 00	
	Insurance on books in Library	30 00	
	Printing postals and notices of meetings	45 90	
	" of Constitution	28 00	
	" receipt books for 1882	6 00	
	Commercial Gazette, for insertion of resolutions on death of Andrew Kloman, Esq	5 40	
	Commissions on $72.50 at 5 per cent	3 62	
	Rent of P. O. box	2 00	
	Total		$ 865 12
	Balance in hands of Treasurer		187 88
			$1,053 00

Respectfully submitted.

ALBERT E. FROST, *Treasurer.*

LIBRARY FUND.

1881.	*Receipts.*		
June 11.	Donation from Wm. Thaw, Esq	$1,000 00	
Nov. 13.	Donation through Wm. Metcalf, Esq	500 00	
	Total		$1,500 00

Brought over		$1,500 00
Expenditures.		
Books, as per vouchers on file	$1,214 07	
Binding	76 10	
Total		$1,290 17
Balance		209 83
Available, but not collected		500 00
Total resources of Library fund		$ 709 83

Respectfully submitted.

A. E. Frost, *Treasurer Eng. Soc'y.*

To the Board of Direction of the Engineers' Society of Western Pennsylvania:

Gentlemen:—I take pleasure in presenting my annual report for the year ending January 17, 1882. The past year, the second since the organization of the Society, has been a very successful one. At the time of my last annual report there were 190 names on the list of members, to which there has been added 57, making a total of 247. During the year 2 have died and 24 have resigned, leaving now on the list 221, or a net gain of 31.

During the year the Society has held nine regular and one adjourned meeting. The dates of the meetings, with the membership and attendance, is as follows:

	Membership.	Present.
January 18, 1881	196	53
February 22, 1881	196	42
March 15, 1881	206	80
April 19, 1881	221	61
May 17, 1881	237	54
September 20, 1881	236	14
September 27, 1881	236	20
October 18, 1881	237	38
November 15, 1881	239	45
December 20, 1881	244	55
Total		462
Average attendance		46

The following papers have been read during the year:

Feb. 22. Notes of a Trip through the James River Valley. By Mr. Jos. D. Weeks.

March 21. The Slide Rule. By Mr. Edwin Thacher.

April 19. A Few of Pittsburgh's Sewers. By Mr. George H. Browne.

May 17. Discussion of Mr. Browne's Paper.

Sept. 27. Discussion Continued.

Oct. 18. Some Wastes of Heat. By Mr. Wm. Metcalf.

Nov. 15. Electricity. By Mr. Jacob Reese.

Dec. 20. An Illustrated Lecture by Prof. A. E. Frost, on Radiant Matter. Description of the Coffer Dam and Means of Puddling at Davis Island Dam. By Mr. Wm. Martin.

The Society, in exchange for its publication, has received the following:

Transactions of the American Society of Civil Engineers for January, February, March, April, May, June, July, August, September and October, 1881.

Journal of the Society of Arts, weekly, from January 1, 1881, to date.

Proceedings of the Engineers' Club of Philadelphia, Vol. II, Nos. 1 and 2, February, 1881.

List of Members, Constitution and By-Laws, and Papers of the Pi Eta Scientific Society, Troy.

Transactions of the American Institute of Mining Engineers, October, 1881.

Proceedings of the Boston Society of Civil Engineers, May, 1881.

Proceedings of Western Society of Engineers, February, 1881.

Abstracts of Papers in Foreign Transactions and Periodicals.

Papers from the Journal of the Franklin Institute.

The American Engineer, December, 1881.

Engineers' Club of Philadelphia.

Journal of the United States Association of Charcoal Iron Workers, August, 1881.

Contributions to the Theory of Blasting or Military Mining, by H. Hofer, (Part Second,) 1881.

Examples of Structures built by the Keystone Bridge Company, Pittsburgh.

Improvement of Non-tidal Rivers. Col. Wm. E. Merrill.

A large number of specifications of Work let in 1881, by the various engineer officers from Maine to California.

Anales de Sociedad Cientifica, Argentina, Buenos Aires, for February, March, April, May, June, July, August, September and October, 1881.

Ingeniors Foreningens Forhandlinger, Stockholm, 5 numbers, 1881.

Revistu de Obras Publicas e Minas Publicaçao Mensal du Associaçao das Enginheiras Civis Portugueses, 1881.

The Committee on Room have continued the arrangements with the Pittsburgh Library Association on the same conditions as for the last year, viz., the Engineers' Society to pay $400 per year to the P. L. A. for the use of a room in which to hold nine monthly meetings, and the members to have the privileges of the library. The P. L. A. have agreed to spend the $400 paid in the purchase of engineering periodicals, but in this they have not fully complied. The following are the papers ordered in this connection, at a total cost of about $115; quite a number, however, were on the Library tables before any agreement was made between the two societies:

1. American Architect and Building News.
2. American Gaslight Journal.
3. American Engineer.
4. Engineering and Mining Journal.
5. Engineering News.
6. Railroad Gazette.
7. Railway Review.
8. Scientific American.
9. Scientific American Supplement.
10. American Journal of Microscopy.
11. American Miller.
12. Bulletin Iron and Steel Association.
13. Carpentering and Building.
14. Eclectic Engineering Magazine.
15. Journal of Chemistry.
16. Journal of Franklin Institute.
17. Manufacturer and Builder.
18. Milling and Mechanical News.
19. Plumber and Sanitary Engineer.
20. Engineer, (London).
21. Engineering.
22. Annales de Mines, (Bi-Monthly).
23. Annales des Ponts et Chaussees, (Monthly).

24. Annalen der Chemie, (Monthly).
25. Civilingenieur, (8 Nos. a year).
26. Journal fur Praktische Chemie.
27. Polytechnisches Journal, (Fortnightly).

During the year the Society has been called upon to part with two of its members, by reason of death, viz., Messrs. J. H. Reno and David Carlin. Suitable memorials have been prepared and entered upon the Minutes of the Society.

Financially, the Society has been a success, as will be seen by the report of the Treasurer.

With the surplus on hand the Board expect during the year to publish the papers in a better form.

During the year the Board of Direction have held ten meetings.

Respectfully submitted.

J. H. HARLOW, *Secretary.*

REPORT OF THE LIBRARY COMMITTEE.

Mr. Wm. Metcalf, President Engineers' Society of Western Pennsylvania:

SIR:—On behalf of the Committee on Library, I have the honor to submit the following report:

As stated in the last annual report of this committee, each one of its members was constituted a sub-committee to prepare a list of books in a special department of technical literature.

Carefully prepared lists were thus obtained, including such works as were considered indispensably necessary for laying the foundation for a library of books upon applied science.

The committee has held a number of meetings, and after a comparison and revision of the lists submitted by its members, it was decided to appropriate as follows:

Bridges and Structures	$280 00
Railroad Engineering	220 00
General Natural Science	200 00
Metallurgy	300 00
Tests of Materials	200 00

Complete sets of the two French periodicals, the "Annales des Mines" and the "Annales des Ponts et Chaussees," have been obtained, at a cost of $260.

Bids were obtained of several Eastern publishers and dealers, and the books purchased of the lowest bidder, at a large discount.

A list of the books has been printed and is now in the hands of members. The committee has at all times invited suggestions from members as to the selection of books, but very few such suggestions were received.

Following is a statement of the finances:

Donation of Mr. Wm. Thaw		$1,000 00
Donation by a friend of the Society, $1.000, of which there has been received		500 00
Subject to draft		500 00
Total		$2,000 00
Expenditures for books		1,290 17
Leaving a balance of		$ 709 83

This balance the committee has decided to dispose of as follows:

Chemistry	$300 00	
German Engineering Works	100 00	
Mining Engineering	150 00	
Thermo-dynamics	50 00	
Hydraulics	50 00	
Leaving still a balance of	$ 59 83	$709 83

According to the arrangement entered into with the Pittsburgh Library Association, June 15, 1880, it was agreed that the $400 to be paid by the Engineers' Society for the use of hall should be devoted wholly to the purchasing of periodicals of a scientific and technical character, for the reading room.

A number of journals have been added to the collection on the tables of the reading room, but the cost of these new journals is estimated at $115.

Respectfully submitted for the committee.

FRANCIS C. PHILLIPS.

REPORT OF COMMITTEE ON TESTS.

To the President of the Society of Engineers of Western Pennsylvania:

SIR:—The Committee on Tests, in the absence of any original work which it is able to lay before the Society, begs leave to submit the following statement of the affairs of the U. S. Commission for the testing of iron, steel and other metals:

In the year 1875, through the exertions of the American Society of Civil Engineers, the American Institute of Mining Engineers, the American Iron and Steel Association, and other scientific bodies, Congress created a Commission to test iron, steel and other metals, and appropriated a sum of money for this purpose. The Commission was composed of one engineer officer of the Army, one officer of the Ordnance Department, two of the Navy, and three civil engineers, and began its labors very auspiciously. A number of tests were made in the Government testing machine at the Navy Yard in Washington, chiefly on chain cables, and a report was published, a copy of which is in possession of the Library of the Society. The chief fruit of the labors of the Commission, however, is represented by the admirable testing machine at the Watertown Arsenal, which it had built, but the use of which it never enjoyed. Even before its completion the funds of the Commission gave out, and all efforts to obtain additional appropriations from Congress proved futile, except so much as was necessary to pay for the machine. After its completion it passed into the hands of the Ordnance Department of the Army, and by a law of Congress was made available to private individuals for purposes of tests, on payment of costs. Extensive use has been made of this privilege, and the Department has also been able to make a limited number of tests on its own account. Among these are the tests on lined and unlined cast iron cylinders subjected to internal pressure, copies of a report on which were furnished the Society through the kindness of Col. Laidley, U. S. A., commanding Watertown Arsenal. Altogether a considerable number of tests have been made, and much information of value could, no doubt, be gathered from them, but very little has been published,

and they as yet await the hand of some one who will work out the results systematically and give proper interpretation to them.

Your committee is happy to state that active steps have been taken by the American Society of Civil Engineers, aided by other societies, in effecting a reappointment of a Commission and securing an appropriation from Congress. At the meeting of the American Institute of Mining Engineers in Washington next month, an united effort will be made to interest members of Congress in the subject, and obtain favorable action during the present session of Congress. It is expected that the new Commission will be placed on a better basis than its predecessor, that its powers will be greater, and that certain errors of organization which impaired the usefulness of the former Commission will be avoided. There is every prospect that these efforts will meet with success, and the near future will see this, the most promising movement made in many years towards advancing our engineering knowledge, again under way and accomplishing results.

The committee regrets that one of its members, Mr. Kent, has been seriously ill for several months, and still continues so, in consequence of which his signature does not appear.

Respectfully submitted.

C. L. Strobel,
J. W. Walker,
Members Committee on Tests.

LIST OF MEMBERS.

Ackenheil, Chas., Chief Engineer Pittsburgh Southern R. R., Pittsburgh, Pa.

Allen, Kennette, P., McK. & Y. R. R., 77 Fourth av., Pittsburgh, Pa.

Amsler, Chas., mechanical engineer, Pittsb'h; Bessemer Steel Works, Homestead, Pa.

Armstrong, Edward, 160 Webster st., Allegheny, Pa.

Armstrong, H. W., Metcalf, Paul & Co., Pittsburgh, Pa.

Aull, Wm. F., box 97, Pittsburgh, Pa.

Awl, Jno. L., Allegheny Valley Railroad, Pittsburgh, Pa.

Backofen, Geo. W., 161 Smithfield st., Pittsburgh, Pa.

Bailey, Reade W., care Robinson, Rea & Co., Pittsburgh, Pa.

Barrett, Jonathan, Ridgway, Elk Co., Pa.

Barrett, Oramel, Jr., Chief Engineer Norfolk & Cincinnati R.R., Marion, Smythe Co., Va.

Barr, Horatio, Supt. Dexter Spring Works, Hulton, Pa.

Barnes, W. H., 262 Penn av., Pittsburgh, Pa.

Bates, Onward, Pittsburgh Bridge Co., Pittsburgh, Pa.

Becker, Max. J., Chief Engineer P., C. & St. L. Ry., Pittsburgh, Pa.

Benner, Matt, Keystone Bridge Co., Pittsburgh, Pa.

Berg, Walter G., Engineer in charge Richmond & Allegheny R. R., Richmond, Va.

Black, Charles, cor. Liberty and Pearl sts., Pittsburgh, Pa.

Blake, F. C., Supt. Penn. Lead Co., Mansfield Valley, Pa.

Bigelow, E. M., City Engineer, Pittsburgh, Pa.

Borntraeger, H. W., Manager of Union Mill, Pittsburgh, Pa.

Boyd, Henry A., National Tube Works, McKeesport, Pa.

Bray, Thos. J., Mech'l Supt. Oliver Bros. & Phillips, South Side, Pittsburgh, Pa.

Brendlinger, P. F., 77 Fourth av., Pittsburgh, Pa.

Browne, Geo. H., P., Ft. W. & C. Ry., Alliance, Ohio.

Brown, W. R., City Engineer's Office, Pittsburgh, Pa.

Brunot, H. H. J., Greensburg, Pa.

Burgher, Rutherford, Crescent Steel Works, Pittsburgh, Pa.

Butz, Jno. A., architect, 86 Third av., Pittsburgh, Pa.

Butz, E. M., architect, Park Way and Federal st., Allegheny, Pa.

Byers, E. M., Byers & Co., Pittsburgh, Pa.

Camp, James M., 131 Rebecca st., Allegheny, Pa.

Carlin, Thos., Lacock and Anderson sts., Allegheny, Pa.

Carnegie, Andrew, 55 Broadway, New York.

Carnegie, T. M., Penn and Homewood avs., Pittsburgh, Pa.

Chess, H. B., Chess, Cook & Co., Pittsburgh, Pa.

Clapp, Geo. H., Black Diamond Steel Works, Pittsburgh, Pa.

Cooper, Chas. A , 269 Liberty st., Pittsburgh, Pa.
Cooper, Jno. W., Robella P. O., Allegheny Co., Pa.
Coulter, J. A., Greensburg, Pa.
Cravath, Robt., Colby, Marathon Co., Wis.
Curry, H. M., Lucy Furnace Co., Pittsburgh, Pa.
Dallas, Chas. R., Moorhead & Co., Pittsburgh, Pa.
Danse, L. O., 4 Eighth st., Pittsburgh, Pa.
Davis, Charles, County Engineer, Court House, Pittsburgh, Pa.
Davis, H. M., 55 Chatham st., Pittsburgh, Pa.
Davison, Geo. S., Ass't Chief Engineer P. C. & Y. R'y, 60 Fourth av., Pittsburgh, Pa.
Dempster, Alex., 89 Fourth av., Pittsburgh, Pa.
Dickinson, H. C., 48 Wood st., Pittsburgh, Pa.
Diescher, Samuel, Sixth st., Pittsburgh, Pa.
Dixon, C. G., 43 Western av., Allegheny, Pa.
Dwight, W. S., Pennsylvania Co., Pittsburgh, Pa.
Eckert, Edward W., Massillon Bridge Co., Massillon, Ohio.
Edeburn, William A., 269 Liberty st., Pittsburgh, Pa.
Edwards, George B., Breed & Edwards, Pittsburgh, Pa.
Ehlers, Chas., Room 8 City Hall, Allegheny, Pa.
Emmerling, Chas., M.D., 314 Penn av., Pittsburgh, Pa.
Engstrom, F., Pennsylvania Co., Pittsburgh, Pa.
Enrich, E. F., Mansfield Valley, Pa.
Felton, S. M., Jr., Gen'l Manager N. Y. & N. E. R. R., Boston, Mass.
Fisher, S. B., Pennsylvania Co., Pittsburgh, Pa.
Frank, Isaac W., Lewis Foundry and Mach. Co., Pittsburgh, Pa.
Fredericks, J. H., Pennsylvania Co., Pittsburgh, Pa.
Frost, Albert E., Walnut st., East End, Pittsburgh, Pa.
Gill, Jno. L., Jr., 83 Wood st., Pittsburgh, Pa.
Gilpin, Arthington, Inspector P. R. R., Harrisburg, Pa.
Glass, George, A. V. R. R., Pittsburgh, Pa.
Goodyear, S. W., Waterbury, Ct.
Gordon, F. W., Water st., Pittsburgh, Pa.
Gottlieb, A., President Keystone Bridge Co., Pittsburgh, Pa.
Griscom, Geo. S., Pittsburgh, Pa.
Gwinner, Fred, jr., Allegheny, Pa.
Hahn, Ign., cor. Fourth and River sts., Sharpsburg, Pa.
Haines, C. W., Cheltenham, Montgomery Co., Pa.
Hall, J. Morton, A. V. R. R., Pittsburgh, Pa.
Harlow, James H., Engineer Monongahela Navigation Co., 81 Wood st., Pittsburgh, Pa.
Harlow, George R., engineer, 81 Wood st., Pittsburgh, Pa.
Hartley, Roger, Hartley & Marshall, Thirty-sixth ward, Pittsburgh, Pa.
Hartupee, W. D., 34 Water st., Pittsburgh, Pa.
Hauck, F., Standard Oil Co., Pittsburgh, Pa.
Hancock, Jno., Black Diamond Steel Works, Pittsburgh, Pa.
Hemphill, James, Mackintosh, Hemphill & Co., foot of Twelfth st., Pittsburgh, Pa.
Hermann, E. A., Pennsylvania Co., Pittsburgh, Pa.
Hill, Albert F., 119 and 121 Nassau st., New York.
Hillard, Chas. J., Duquesne Way, Pittsburgh, Pa.

Hoff, Olaf, Tampico, Mexico.
Hoffstot, Frank N., iron commission merchant, 92 Fourth av., Pittsburgh, Pa.
Hunt, A. E., Assistant Manager Black Diamond Steel Works, Park Bros. & Co., Pittsburgh, Pa.
Jackson, C. A., Keystone Bridge Co., Pittsburgh, Pa.
Jarboe, Walter S., 81 Wood st., Pittsburgh, Pa.
Jennings, Benjamin F., of Smith, Sutton & Co., Pittsburgh, Pa.
Jones, B. F., Jones & Laughlins, Pittsburgh, Pa.
Jones, Jenkins, Campbell & Jones Pittsburgh, Pa.
Jones, T. M., American Iron Works, Pittsburgh, Pa.
Jones, Wm. R., box 1461 Pittsburgh, Pa.
Jope, Geo. W., Soho Iron Works, Pittsburgh, Pa.
Kay, J. C., Kay Bros. & Co., Pittsburgh, Pa.
Kaufman, Gustave, 16 Cedar av., Allegheny, Pa.
Kent, Wm., mechanical engineer, 91 Fourth av., Pittsburgh, Pa.
Kenyon, L H., Soho Works, Pittsburgh, Pa.
Kerr, Wm., 188 Webster av., Pittsburgh, Pa.
Kerr, T. B., 110 Diamond st., Pittsburgh, Pa.
King, T. M., Pittsburgh, Pa.
Kirk, Arthur, 19 Seventh st., Pittsburgh, Pa.
Kloman, Chas. H., box 802 Pittsburgh, Pa.
Laing, Geo., Penn av. and Tenth st., Pittsburgh, Pa.
Laughlin, F. B., Pittsburgh, Pa.
Leschorn, Alex., Keystone Bridge Co., Pittsburgh, Pa.
Lewis, F. H., Pennsylvania Co., Pittsburgh, Pa.
Lewis, J. L., Pittsburgh, Pa.
Lewis, W. J., Hazelwood Oil Co., Pittsburgh, Pa.
Lindenthal, Gustave, bridge engineer, 77 Fourth av., Pittsburgh, Pa.
Lindsay, Jas. H., 98 Rebecca st., Allegheny, Pa.
Link, Theodore, C., 135 Smithfield st., Pittsburgh, Pa.
Linton, Wm. H., Pennsylvania Co., Pittsburgh, Pa.
Livingston, Max., Supt. Standard Oil Co., box 538 Pittsburgh, Pa.
Loomis, Geo. P., Crescent Steel Works, Pittsburgh, Pa.
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